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SOUTH COASTAL BASIN INVESTIGATION

GEOLOGY

AND

GROUND WATER STORAGE CAPACITY OF VALLEY FILL

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The geology for the Geologic Map and sections, Plates A, B, C, and D, were compiled from both published and unpublished sources. The published sources are as follows:

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Eckis, R., Alluvial Fans of the Cucamonga District, Southwestern San Bernardino County, California, Jour. Geology, Vol. 36, 1928.

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FOREWORD

The geologic studies carried on during the past four years in connection with the South Coastal Basin Investigation have had as their primary object the determination of the nature of the various underground basins, and geologic conditions pertaining to the movement and storage of ground water in them. Special emphasis has been laid upon the problem of working out reasonable storage capacity estimates so that water table fluctuations might be evaluated in terms of storage change.

It has become increasingly evident, with the long continued decline of the water table in most basins, and with the important place ground water has come to play in the water supply of the region, that a proper quantitative evaluation of water table fluctuations is essential to the proper conservation and economic utilization of these waters.

Through the kindness of President C. K. Edmunds and Professor A. O. Woodford, both of Pomona College, equipment and laboratory space in the Geology department of the college were made available to the Division of Water Resources for experimental research to determine the water-bearing properties of the various types of material that make up the ground water basins of the region.

The results of office, field and laboratory studies pertaining to storage capacities in the valley fill, together with detailed descriptions of the geologic conditions in the individual basins, and a general description of the geology of the South Coastal Basin are presented in the following pages.

It is not thought that the results on specific yield of the basins herein given are final but they are believed the most reliable yet achieved for the area involved. It may be that close attention to input and output of water and change in water table will at some time in the future modify the values found in this study.

GEOLOGY

AND

GROUND WATER STORAGE CAPACITY OF VALLEY FILL

CHAPTER I

INTRODUCTION

The South Coastal Basin of California includes the Coastal Plain areas of Los Angeles and Orange counties, together with the inland drainage areas of the Los Angeles, San Gabriel and Santa Ana rivers, exclusive of the San Jacinto River drainage area, which is tributary to Santa Ana River. The entire South Coastal Basin has an area of approximately 2,500,000 acres. Of this, about 45 per cent (principally the valley land) overlies productive ground water basins. About 70 per cent of these lands are irrigated or using domestic and industrial water. The rapidly increasing population of the area has now reached about 2,800,000 people.

Climate.

The average rainfall on the valley lands ranges between about 10 and 25 inches annually, the higher portions near the mountains receiving more than the low coastal area. In the mountain areas the rainfall is considerably higher, averaging from 20 to about 40 inches annually. Practically all of the rainfall occurs between the months of October and May. The summer months are warm and dry. Irrigation of crops is necessary during these months and in years of deficient rainfall, irrigation may be necessary throughout a considerable part of the winter in certain areas.

Run-off and Surface Water Supply.

Although about half the area is valley and low hill land, probably two-thirds of the total precipitation falls in the mountains, and a considerably greater part of the total run-off originates there. The mountains are characteristically steep and rocky; the storms are often heavy, concentrating a large part of the season's rainfall into a few days. Consequently, heavy flood flows discharge from the canyon mouths for short periods onto the gravel cones of the valleys. Although there is considerable waste into the ocean during major floods, percolation of these flood waters into the ground water basins constitutes the greater part of their supply. Percolation of rainfall upon the valley floor during periods of excessive rainfall is also an important source of supply.

The precipitation in normal years is sometimes and in subnormal years is frequently so well distributed throughout the rainy season that little or no run-off and little rainfall percolation results. In such years there is practically no recharge of the ground water basins, except locally near the larger canyon mouths.

Summer flow in the mountain canyons dwindles to a minimum during the time when demand is greatest, and little has been done toward supplementing it by surface storage reservoirs, as in general such reservoirs are prohibitively expensive.

Functions of the Ground Water Basins.

The summer demand for water by municipalities and irrigators is so heavy that the diverted surface flow of streams and stored surface waters are able to furnish only about 10 per cent of the supply from local sources. About 90 per cent of the supply originating within the South Coastal Basin comes from the ground water basins. The capacities of most of the ground water basins are so great that they store large excesses of ground water during years of heavy rainfall and run-off, to be utilized during years of subnormal rainfall.

Nature of the Ground Water Problem.

The total surface area of those portions of the ground water basins in which changes of storage take place is about 840,000 acres and in this area it is estimated that every foot average rise or fall of the water table represents something like 70,000 acre feet change in the amount of underground water. Since there are several hundred to more than a thousand feet of pervious materials below the present water table in all the larger basins, and as present pumping wells generally penetrate to a considerable distance below the water table, it can be seen that there are many millions of acre feet of stored water within their reach. A statement such as this might be misleading and must be qualified by the further statement that there is no uniformity in magnitude of fluctuations of ground water over the entire area. In general, but not always, however, the water tables of all basins change in the same direction in the course of a year.

When development of the ground waters first began there was an excess rising to the surface at the outlets of all the principal basins, and artesian pressures existed in many places. Artesian water was obtained over a large part of the central and southern Coastal Plain. These surpluses have been gradually reduced over a long period of years together with a gradual depletion of the stored ground water. However, the storage capacities are so great, compared to the annual changes of storage, that the decline has been gradual and difficult to evaluate.

Although the storage capacity of the basins at first seemed almost unlimited, it has become increasingly evident that this is not true. The city of Los Angeles, some years ago, found it necessary to bring water in from Owens Valley to supply its increasing needs. More recently it has gone into the Mono Basin for additional supplies.

Now the Metropolitan Water District is preparing to bring in enough water from the Colorado River to supply the present overdraft and to provide for a long period of future expansion. However, there is not at present a universal overdraft in the South Coastal Basin. Ground water is being drawn from 37 rather distinct ground water basins in the area, and although ground water conditions in these are more or less interdependent, the physical characteristics and local supply and demand make each basin a problem in itself. If past rate of replenishment is a criterion there is clearly a surplus of ground water in some basins today, in other basins alarming shortages have developed, and it is necessary to determine for each basin whether a permanent overdraft exists, and if not, whether and when the condition is likely to develop.

A proper evaluation of the changes of storage represented by the rise and fall of the water table is essential to the correct interpretation of the present situation, and to possible predictions of future trends.

Scope of the Geological Investigation.

The geological investigation has not been concerned with the actual determination of overdrafts or surpluses in the various ground water basins, but rather, it has been carried out for the purpose of determining: First, the geological conditions, including the nature of the basin boundaries, the physical character of the basins themselves and their relation to the occurrence and movement of ground water; and second, storage capacity estimates for each basin, in order that the rise and fall of the water table can be interpreted in terms of storage changes.

The geological investigation included several lines of study. These are outlined briefly as follows:

1. *Experimental work.* Several hundred samples of typical gravels, sands and clays of the South Coastal Basin were dug from surface exposures, and obtained from post hole borings. About 2000 samples of similar materials were collected from wells as they were being drilled. Porosity determinations were made of the samples taken in place, and of those which came intact from wells. Further experimental work was done to determine the water-yielding capacity of various materials, and the coarser sediments were classified by mechanical analysis. The nature of this work and its results are described in Appendix I.

2. *Subsurface studies.* About 5000 well logs from all parts of the basin were collected. Nearly 300 wells were observed as they were being drilled. The well logs were grouped and the materials classified with the aid of notes from wells observed during drilling. Thus by grouping the well logs and averaging the materials, the vertical and horizontal distribution of water-bearing materials was estimated. Combining this information with yield values obtained by the experimental work, storage capacities of the basins were computed. Plate E in pocket shows the result of this work. The well logs were used further to determine, where possible, the contour of the bedrock floors of the basins. Bedrock contours are shown on Plates A, B, and C in pocket.

3. *The Geological Map.* Areal geology was compiled from all available sources, including both published and unpublished data. The unpublished material was obtained in large part from oil companies, but many individuals contributed also. Where information was not available, and especially in the ground water basin areas, where the geological details were a direct concern of this investigation, the mapping was done by the Division as a part of the basin studies. For presentation in this report, geologic mapping obtained from the various sources was coordinated and modified to show the distribution of water-bearing formations and their relation to nonwater-bearing formations. The geologic map and sections are shown on Plates A-D, inclusive, in the pocket.

Summary of Areas, Storage Capacities and Specific Yields.

Specific yield and storage capacity studies were made in 35 ground water basins of the South Coastal Basin. A few of these basins were further subdivided into areas. The specific yield and storage capacity figures appearing in this report are based upon a zone averaging 50 feet thick above the water table of January, 1933, and 50 feet thick below that water table. In most basins the zones did not have a uniform thickness but were varied to take into account the relative differences of water table fluctuations in different parts of the basins.

In Table 1, the areas and storage capacities of the 35 basins are summarized. In the surface area column, as noted, portions of certain basins not subject to storage change are excluded. The surface areas are in many basins larger than the areas of the corresponding 1933 water tables (effective areas of the 100 foot storage capacity zones) due to the convergence of the bedrock slopes downward, and therefore in such cases the areas in Table 1 are not direct factors of the storage capacities shown.

In some basins the limited vertical range of water-bearing deposits, above or below the water table, made it necessary to restrict the zones to fractional parts of the usual 50 feet. In such cases the thicknesses used are noted.

The estimated average specific yields of the 100 foot zones, shown in the last column of Table 1, are weighted on the basis of variable thicknesses of the zone, and therefore do not necessarily represent the same average figure that might be obtained by using a zone uniformly 100 feet thick with the contours on Plate E in the pocket.

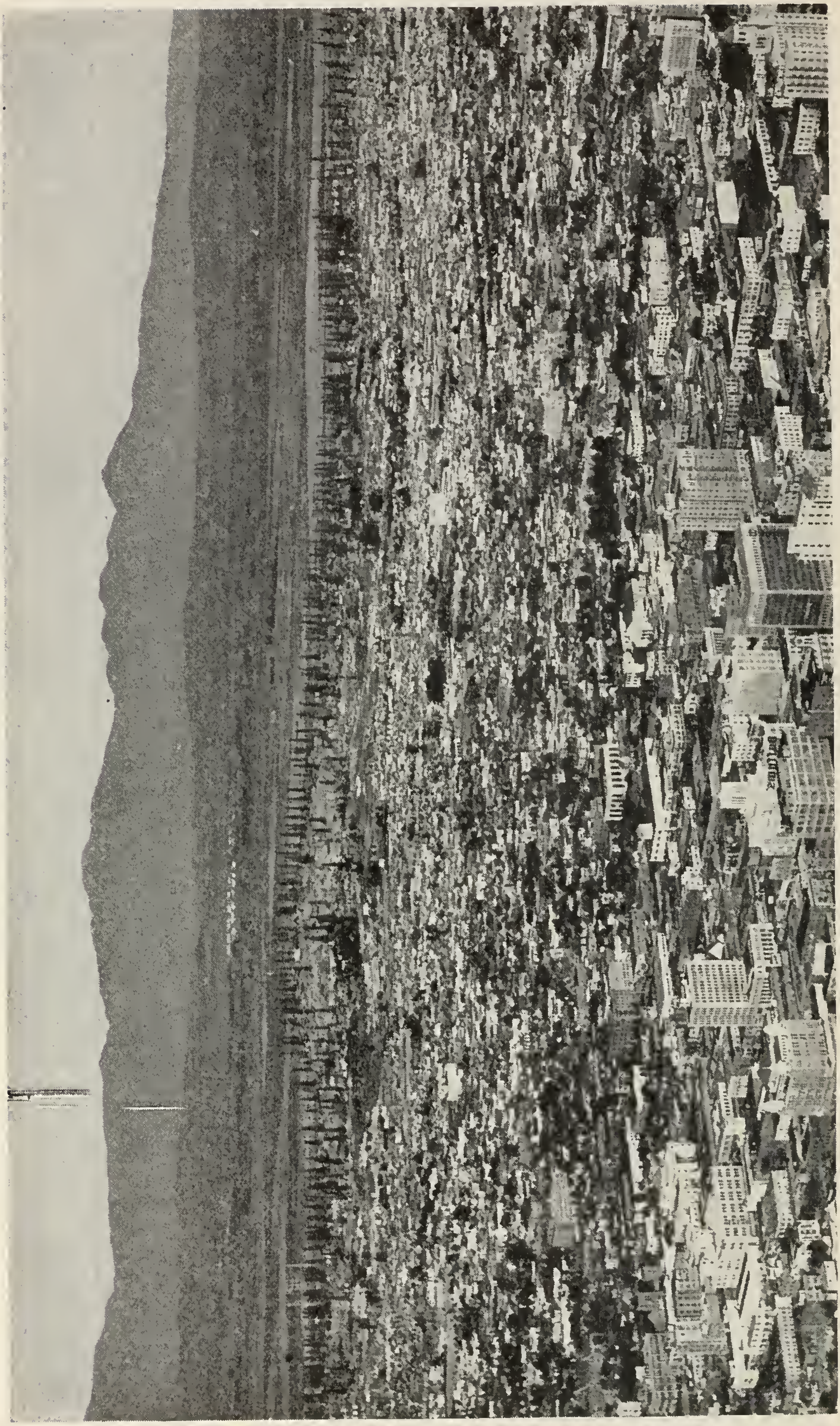
TABLE 1

AREAS, SPECIFIC YIELDS, AND GROUND WATER STORAGE CAPACITIES IN SOUTH COASTAL BASIN

Ground water basins	Surface areas	Storage capacity in acre-feet			Approximate specific yield of 100-foot zone
		50-foot zone above water table	50-foot zone below water table	Total 100-foot zone	
San Fernando Valley					
1. San Fernando	96,200	405,000	412,000	817,000	9.0
2. Sylmar	6,700	20,000	24,000	44,000	7.0
3. Tujunga	7,330	23,000	20,000	43,000	8.0
4. Pacoima	2,870	11,000	12,000	23,000	8.0
5. Verdugo	3,840	8,900	7,600	17,000	5.5
Totals	116,940	468,000	476,000	944,000	
San Gabriel Valley					
6. Main San Gabriel	73,400	422,000	419,000	841,000	11.5
7. Monk Hill	4,990	18,000	17,000	35,000	7.5
8. Raymond—					
8a. Pasadena area	15,000	65,000	62,000	127,000	9.0
8b. Santa Anita area	2,900	9,500	9,500	19,000	7.0
9. Upper Canyon	1,260	6,000	5,100	11,000	11.0
10. Lower Canyon	1,580	9,200	9,000	18,000	11.5
11. Glendora	2,680	10,000	9,300	19,000	8.0
12. Way Hill	1,700	7,300	4,500	12,000	10.5
13. San Dimas	5,000	17,000	15,000	32,000	7.5
14. Foothill	1,150	----------	----------	----------	----------
15. Puente	10,900	29,000	28,000	57,000	6.0
Totals	120,560	593,000	578,000	1,171,000	
Upper Santa Ana Valley					
16. Chino	(a) 129,500	536,000	583,000	1,119,000	9.0
17. Claremont Heights	3,220	9,400	9,000	18,000	6.0
18. Live Oak	1,730	4,100	4,000	8,100	5.0
19. Pomona	5,540	16,000	17,000	33,000	6.5
20. Cucamonga	7,940	27,000	27,000	54,000	7.0
21. Rialto-Colton—					
21a. Rialto	14,420	60,000	60,000	120,000	8.5
21b. Colton	8,210	50,000	43,000	93,000	11.5
22. Bunker Hill	(b) 50,950	257,000	243,000	500,000	10.0
23. Lytle	3,940	22,000	22,000	44,000	11.0
24. Devil Canyon	6,300	26,000	21,000	47,000	7.5
25. Yucaipa-Beaumont—					
25a. Yucaipa	13,960	48,000	51,000	99,000	7.0
25b. Beaumont	13,060	29,000	31,000	60,000	5.0
26. San Timoteo—					
26a. North area	15,180	----------	48,000	(c) 48,000	(c) 6.5
27. Riverside	32,160	(d) 51,000	156,000	(e) 207,000	(e) 11.0
28. Arlington	14,180	(f) 14,000	(f) 22,000	(c) 36,000	(c) 9.5
29. Temescal	16,170	(f) 34,000	(f) 36,000	(c) 70,000	(c) 9.0
30. Spadra	4,200	15,000	11,000	26,000	7.5
Totals	340,700	1,198,000	1,384,000	2,582,000	
Coastal Plain					
31. West—					
31a. Northern area	26,750	144,000	144,000	288,000	----------
31b. Southern area	(g) 62,070	(f) 201,000	(f) 201,000	(c) 402,000	----------
32. Hollywood	9,450	20,000	18,000	38,000	5.0
33. Central—					
33a. Los Angeles River area	(g) 31,030	152,000	152,000	304,000	----------
33b. San Gabriel River area	(g) 24,830	142,000	162,000	304,000	12.0
33c. Santa Ana River area	(g) 46,130	261,000	231,000	492,000	11.0
33d. Irvine area	(g) 24,940	64,000	62,000	126,000	5.5
34. La Habra—					
Upper zone	21,100	40,000	40,000	80,000	4.5
Lower zone	----------	33,000	40,000	73,000	12.0
35. Yorba Linda	(h) 11,100	30,000	27,000	57,000	5.0
Totals	257,400	1,087,000	1,077,000	2,164,000	
TOTALS, SOUTH COASTAL BASIN	835,600	3,346,000	3,515,000	6,861,000	

(a) Portion not included in storage change (18,700 acres), in southwest corner of basin is excluded.
(b) Portion not subject to storage change (6,270 acres), shown on Plate E in pocket, is excluded.
(c) Average thickness of zone is only 50 feet.
(d) Average thickness of zone is only 20 feet.
(e) Average thickness of zone is only 70 feet.
(f) Average thickness of zone is only 25 feet.
(g) Includes only area in which storage change occurs (Plate E in pocket).
(h) Includes upper zone only.

PLATE I



Looking northeast across South Coastal Basin. Long Beach and Signal Hill in foreground. Central Coastal Plain beyond. Puente Hills in middle distance and San Gabriel Mountains in background.

Spence Airplane Photo

CHAPTER II

GENERAL GEOLOGY

Within the South Coastal Basin there are three main inland structural subbasins (San Fernando, San Gabriel and Upper Santa Ana valleys) which are filled with absorptive alluvial deposits, underlain and surrounded by relatively impervious rock. They form natural ground water storage reservoirs for the rainfall and run-off that percolates into them. The Coastal Plain forms another great structural basin, or more properly speaking, several basins filled with absorptive marine and alluvial sediments. The central basin of the Coastal Plain, lying east of the row of low hills extending southeast from Inglewood to Huntington Beach, forms a reservoir which collects the underground and a part of the surface waters that escape from the three inland basins. The western Coastal Plain basin receives a limited underflow from the eastern basin, but in the main is supplied by local rainfall percolation and run-off from adjacent areas.

In general, the course of the underground water in moving from the mountains toward the sea follows the direction of the surface streams. It moves very slowly, however, as a body through the pervious beds, and its progress is interrupted by many geologic structures (faults and folds) which form local subbasins. Each structural subbasin acts somewhat as a ground water unit and a study of the geologic conditions and their effect upon the ground water in each of these subbasins was therefore made.

PHYSIOGRAPHY

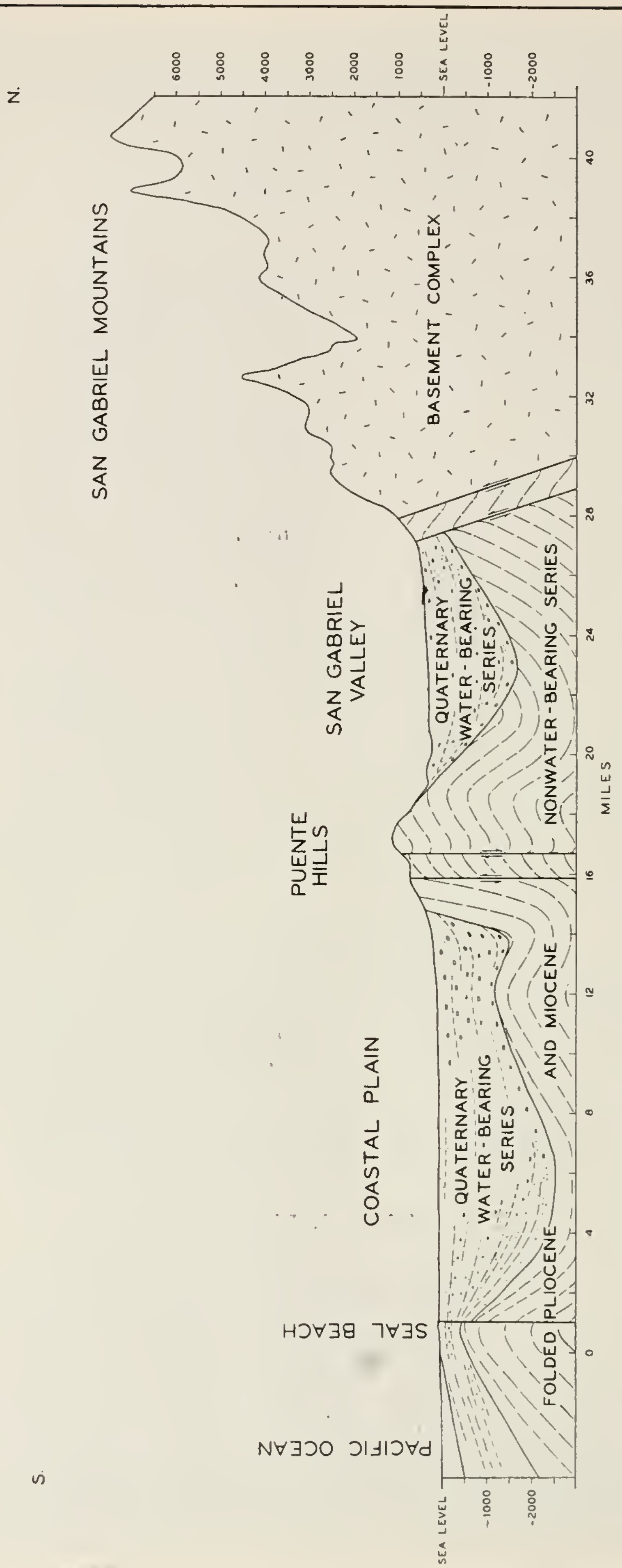
The South Coastal Basin has four physiographic divisions, namely (1) the Coastal Plain; (2) an intermediate belt of hills and low mountains from the Santa Monicas to the San Joaquin Hills that form a semicircle about the Coastal Plain; (3) the three inland alluvial plains or valleys—San Fernando, San Gabriel and Upper Santa Ana; and (4) the high San Gabriel, San Bernardino and Santa Ana mountain ranges. These four divisions are shown in the diagrammatic section, Plate II.

THE COASTAL PLAIN

The Coastal Plain has a length of about 50 miles and a width of 12 to 20 miles. With the exception of the San Pedro Hills, which rise 1500 feet above sea level as an isolated mass at the coast line, its surface is broken only by occasional hills and low mesas. In its eastern part it has been built up during late Pleistocene and Recent geologic time from a shallow sea bottom, by the outwash cones of the streams that drain from the interior. In its western part it is the uplifted and modified floor of the sea itself.

Oscillations of sea level, together with differential movement of the land, have in some places left the surface of the plain well above the

PLATE II



DIAGRAMMATIC SECTION ACROSS SOUTH COASTAL BASIN
SHOWING
THE FOUR MAJOR PHYSIOGRAPHIC DIVISIONS

present level of deposition, and in other places have submerged it below this level. Those areas that have been uplifted stand as hills, terraces, or mesas undergoing dissection, and are characterized by weathered, usually red or brown, soil surfaces. In the areas of subsidence, alluvial debris is actively accumulating and the surface is covered by relatively little-weathered sandy or silty soil.

Most prominent among the dissected areas are two rows of hills produced by recent folding and faulting of the plain surface. One, the Beverly-Newport uplift, is a row of hills which extends southeasterly from Beverly Hills to Newport Beach, and includes the Baldwin Hills at Inglewood, Dominguez Hill, Signal Hill, Landing Hill, Huntington Beach Mesa and Costa Mesa. The other row of hills lies along the axis of the Santa Fe Springs-Coyote uplift. It begins at Santa Fe Springs, south of Whittier, with scarcely perceptible topographic expression and culminates in the Coyote Hills several miles to the east.

Westward from the Beverly-Newport uplift the Coastal Plain is dissected by the present streams to depths of 25 to 100 feet. The dissected areas are broad, flat mesa or terrace-like remnants of an uplifted late Pleistocene marine surface, that stretches from the row of hills along the east to the ocean on the west, where it ends abruptly in a series of bluffs. At its northern margin this old marine surface is contemporaneous with deeply dissected alluvial cone surfaces along the base of the Santa Monica Mountains.

Between the San Pedro Hills and Santa Monica there is a series of old sand ridges parallel to the coast, which originally was, at least in part, a series of offshore sand bars upon the ocean floor. These old sand bar ridges are probably the source of the sand dunes that cover the area southwest of Inglewood. If so, they have, in that area, been so modified by wind erosion that their original form is hardly recognizable.

On the low parts of the old marine surface slight thicknesses of alluvium have accumulated from dissection of nearby higher portions, but in the main there has been no appreciable alluvial deposition upon the old marine surface since its uplift from the ocean bottom.

The streams which dissect the western Coastal Plain now flow across broad flood plains (incised into the old marine surface) but slightly above sea level, and empty into sloughs with marshy tide lands. These sloughs at the mouths of the present streams indicate subsidence, and it therefore seems probable that the western Coastal Plain in the recent geologic past stood higher above sea level than it does today, and that the streams flowed in canyons which are now filled with estuarine and flood plain deposits.

The Beverly-Newport uplift marks an important physiographic break in the Coastal Plain. The Pleistocene marine surface which to the west is faulted and folded up over this row of hills, dips down on the east side and passes beneath Recent alluvium. East of the Beverly-Newport uplift the Coastal Plain is an undissected Recent alluvial surface extending from the base of the Santa Monica Mountains for 50 miles southeasterly to the vicinity of Irvine. This surface, narrow at the two ends, reaches a maximum width of nearly 15 miles near the center.

This area of undissected alluvium is the surface of a great trough into which the three principal rivers and the minor streams are pouring their debris. Water well data show this trough to contain at least

1500 feet of poorly consolidated marine sands, gravels and clays (shallow water deposits) along most of its axis, with a comparatively thin series of alluvial sediments on top. These materials, probably all Upper Pleistocene and Recent deposits, indicate that subsidence has accompanied deposition and only comparatively recently has the basin become filled above sea level.

The Santa Fe Springs-Coyote uplift near the northeast margin of the Coastal Plain has separated the narrow depression (generally known as the La Habra Basin) north of it from the main Coastal Plain, so that this trough has filled with alluvial materials from the nearby hills as it subsided, while a large part of the main Coastal Plain was filling with marine sediments.

Older alluvium has been folded up over the uplift and together with part of the depression north of it now stands above the level of deposition on the central Coastal Plain. The alluvium in this area is thus dissected and has developed a reddish-brown soil surface.

Elsewhere between the principal rivers, dissected alluvial cones with weathered reddish-brown soil surfaces fringe the north, east and south margins of the Coastal Plain. The surfaces of these dissected cones, steeper at their apices than the present streams, converge with them toward the center of the Coastal Plain and finally pass beneath them. These older alluvial cone surfaces are approximately equivalent in age to the old marine surface of the western Coastal Plain.

Marine Terraces.

Dissected remnants of old marine terraces (elevated shorelines) occur along the coast beyond both the northwest and southeast ends of the Coastal Plain, and again along the southwest side of the San Pedro Hills where they are excellently developed. Seven or eight well-defined old shorelines, and several other rather indistinct ones can be recognized in the San Pedro Hills. The highest terrace remnants in this region, are rather indistinct, and are more than 1000 feet above sea level.

In general, the marine terraces in the vicinity of the Coastal Plain are practically undeformed and it has been suggested that they represent general continental uplift, or oscillation of sea level since the major deformation that has folded the Tertiary sediments. However, the terraces at different places along the coast are not at corresponding elevations. Consequently, even though oscillation of sea level may have been a factor, other forces more local have elevated different areas independently.

These terraces, so well developed where the hills meet the ocean. are not found along the hills that encircle the inner margin of the Coastal Plain. There is a belt of alluvium in front of these hills, which water well logs show to extend in most places to depths of several hundred to 1000 feet or more below sea level, and to interfinger horizontally toward the central part of the Coastal Plain with the later marine beds beneath the surface there. Evidently then, any terraces that were formed around the inner margin of the plain were cut into the protecting alluvial apron in front of the hills and were buried as this alluvium subsided, just as the terraces that were cut into rising areas emerged.

Woodring[1] has pointed out one locality where deposits on the youngest well-defined terrace at the San Pedro Hills are tilted 26 degrees toward the basin and marine deposits equivalent to these at San Pedro Hills are gently folded along the Beverly-Newport uplift.

It would seem from these bits of evidence that certain areas have risen while others have subsided during late Pleistocene time, and that deformation has occurred principally in the transition zones between the areas of uplift and those of subsidence. The practically horizontal terrace remnants were cut into relatively stable parts of the uplifted areas.

THE INTERMEDIATE BELT OF HILLS

Between the Coastal Plain and the inland plains there is a belt of hills and low mountains which break up the inland plains into three separate valleys. (See Plate E, in pocket.) This group of hills includes the Santa Monica Mountains, the Verdugo, San Rafael, Merced, San Jose and Puente hills, and the north end of the Santa Ana Mountains. These hills are in the main made up of folded Tertiary sediments with granitic rocks in the more mountainous areas. The hills are maturely dissected throughout and their short streams for the most part enter directly onto the plains where they have contributed relatively minor amounts of alluvium to the basins. The San Joaquin Hills, though separated, are comparable to those of the intermediate belt.

The Los Angeles River flows southeasterly through these hills from the east end of San Fernando Valley onto the Coastal Plain, passing between the Santa Monica Mountains and the low hills to the east. The narrows through which it flows is an alluviated valley about one mile wide. The floor of the alluvial fill beneath the river is little more than 100 feet deep where the river runs through the hills, but drops off sharply at both ends. The river is apparently an antecedent stream that maintained its course across the hills as the basins on either side subsided and as the hills rose during Upper Pleistocene time. Apparently the gradual rise of the alluvial surface on the Coastal Plain has caused the river to deposit 100 feet or more of alluvium through its channel into the San Fernando Valley.

Near the lower end of the Los Angeles River Valley the Arroyo Seco joins it. The Arroyo Seco has throughout most of its history been tributary to the San Gabriel River, but the rising level of alluvium in San Gabriel Valley finally topped the hills along the southwest side and the Arroyo Seco stream ran out through a gap in these hills into the low Los Angeles River.

The San Gabriel River and its distributary, the Rio Hondo, flow through the Whittier Narrows at the west end of the Puente Hills. The narrows is a broad V-shaped depression in the hills filled to the depth of 1000 feet or more with alluvium. The width at the narrowest point is a little less than two miles. The floor beneath the alluvium is deeper both toward San Gabriel Valley and toward the Coastal Plain. In contrast to the relatively shallow fill in the Los Angeles River Narrows, this great depth of alluvium in the Whittier Narrows suggests that subsidence has accompanied accumulation of the alluvium.

[1] Woodring, W. P., San Pedro Hills, Int. Geol. Congress Guidebook 15, Southern California. P. 38 and Fig. 5, 1932.

The structure in the hills on either side tends to substantiate this view. On the northwest side of the narrows the east-west Montebello anticline plunges toward the narrows, and on the southeast side the strata dip toward the narrows.

The Santa Ana River flows from the Upper Santa Ana Plains to the Coastal Plain in a canyon which separates the Puente Hills from the north end of the Santa Ana Mountains. The canyon has a somewhat winding course about nine miles long. It is filled with river sands and gravels to the rather uniform depth of 80 to 100 feet. The flood plain floor of the canyon has a variable width, from about one-fourth mile near its upper end to about one mile at its lower end.

Like the bedrock floors of both the Los Angeles and San Gabriel River narrows, the bedrock floor of Santa Ana Canyon drops away to a greater depth both above its head and below its mouth. The stream is antecedent to the hills through which it flows, having maintained its course during uplift and formation of the hills. A series of gravel terraces on both sides of the river record stages of rest in the uplift and down-cutting of Santa Ana River.

THE INLAND PLAINS

The three large inland valleys or alluvial plains are in many respects similar to the Coastal Plain. These plains are the complex surfaces of coalescing alluvial cones of the streams that drain the higher areas surrounding the basins. Like the Coastal Plain their relatively flat surfaces are in marked contrast to the mountains and hills which rise abruptly from their margins. The central low parts of these basins are regions of active deposition, practically unbroken by hills or incised washes. High remnants of dissected cones fringe the mountains, and lower dissected cones in some areas extend well out into the valleys, finally merging with the undissected alluvium.

Occasional bedrock hills protrude through the alluvium, and in other places the even floors of the valleys are broken by low alluvial hills and mesas produced by recent faulting or folding of the alluvium.

San Fernando Valley.

The San Fernando Valley is a triangular plain 20 miles long in an east-west direction that widens from about three miles at the western end to 10 miles at the eastern end. The eastern half of the valley is covered by the pervious granitic gravel cones of Big and Little Tujunga rivers and Pacoima Creek. The western half of the valley is covered by the less pervious cones of the smaller streams that drain the sedimentary hills around the western part of the valley. The Los Angeles River rises at the western end of the valley, flowing easterly along the south side and out through the hills at the extreme southeast corner.

Practically the entire San Fernando Valley is at present an area of active alluvial deposition. The comparatively little-dissected alluvium is almost entirely in the northern part of the valley. One area about four miles southwest of San Fernando comprises a slight anticlinal rise along which the Older alluvium has been uplifted above the general level of deposition. Northeast of San Fernando, Pacoima Creek has dissected its cone-head and the dissected portion has developed the reddish-brown soil typical of the Older alluvium. Elsewhere about the valley margin there are occasional small terrace remnants of older gravels at high levels.

There is a neck of alluvium between the San Gabriel Mountains and the Verdugo Hills, filling the La Canada structural trough, that connects the northeast corner of San Fernando Valley with the northwest corner of the San Gabriel Valley. Steep alluvial cones of granitic and gneissic debris, sloping south from the San Gabriel mountain-front, fill this trough to the depth of several hundred feet. A group of low bedrock hills protrude through the alluvium near the middle of the alluvial neck and form a natural underground divide between the two valleys.

San Gabriel Valley.

The San Gabriel Valley is a broad alluvial plain with a gentle southerly slope. Its greatest length, in an east-west direction, is a little more than 20 miles, and its width, greatest at the west end, is 7 to 10 miles wide for most of its length but narrows to little more than two miles at the eastern end.

This relatively flat alluvial plain forms a striking contrast with the rugged steeply sloping San Gabriels to the north and with the lower hills that form the other margins. However, in detail the alluvial floor is itself broken up by areas of dissected alluvium. The debris cone of the San Gabriel River occupies the central part of the valley extending from the mountain canyon mouth across the valley through the Whittier Narrows to the Coastal Plain. This area is one of active deposition. The area of active deposition extends east and west for some distance on either side of the San Gabriel Cone, the adjacent areas being covered by Recent alluvial debris of the smaller streams that drain the San Gabriels. However, dissected Older alluvium covers most of the eastern and western parts of the valley and occurs elsewhere about the margins. On the west side of the valley, Arroyo Seco having abandoned its cone, the principal source of deposition has been removed, and this factor together with uplift of the Pasadena-Sierra Madre area, north of Raymond fault (see Plate A, in pocket), has caused general dissection of the western one-third of the valley floor and consequent development of a weathered reddish-brown soil on the dissected area. Uplift along the San Gabriel mountain-front has caused the cone-heads to be dissected, and many high remnants of the old cones fringe the mountain-front between the canyon mouths. San Dimas Cone, which covers the floor of the narrow eastern part of the basin, is deeply dissected by the present stream, being incised to the depth of 125 feet at the cone-head. Gradually toward the central San Gabriel Valley the old dissected surface merges with the present surface of deposition. However, the old surface extends southwesterly along the edge of the San Jose Hills for several miles.

Occasional bedrock prominences protrude through the alluvium, forming steep-sided hills which contrast sharply with the flat alluvial surfaces around them. These hills are in every case comparatively near to the edge of the valley and their occurrence generally marks regions of relatively shallow alluvium. The alluvial fill in San Gabriel Valley has been found by well drilling to be between 1000 and 2000

PLATE III

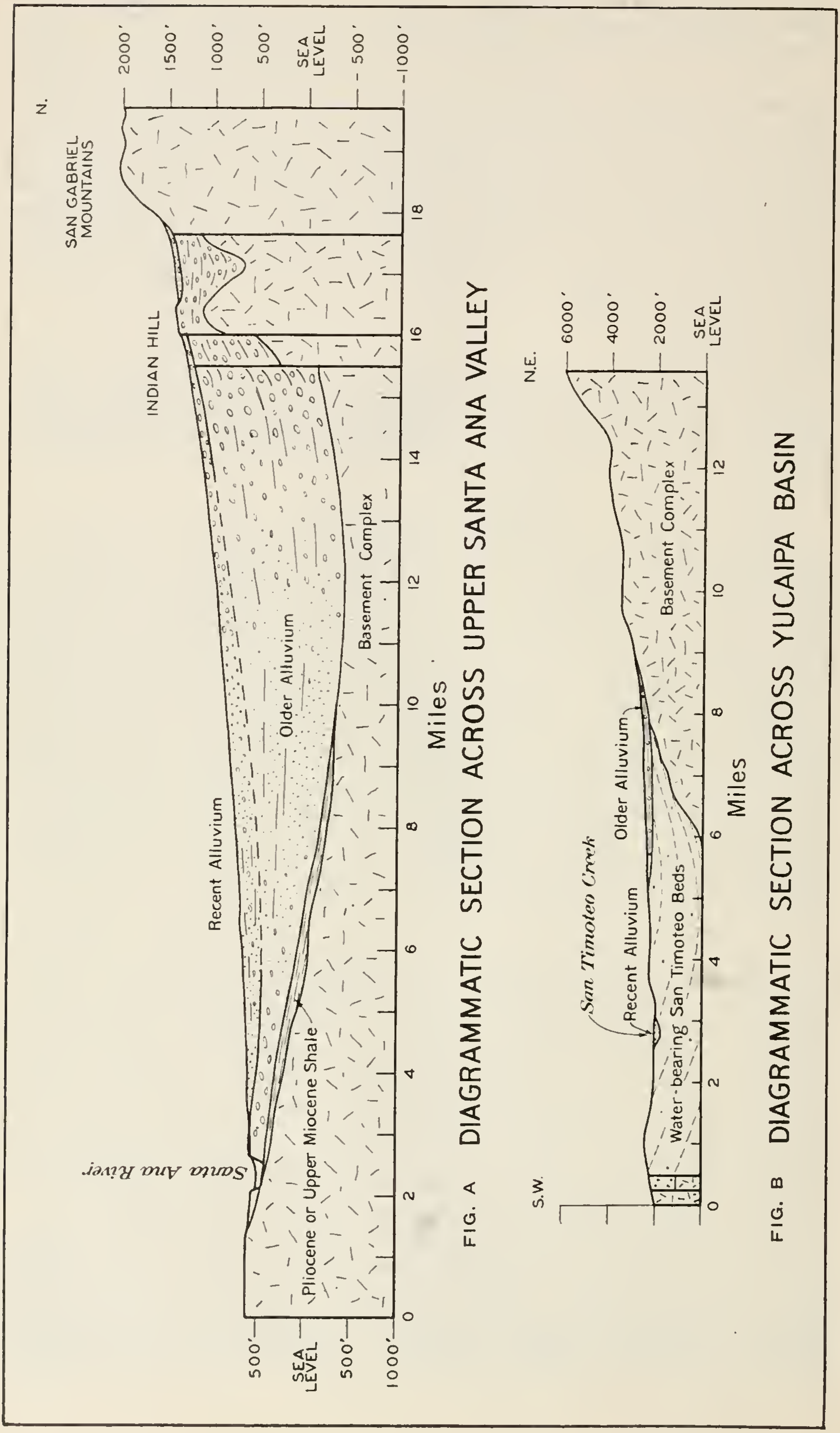


FIG. A DIAGRAMMATIC SECTION ACROSS UPPER SANTA ANA VALLEY

FIG. B DIAGRAMMATIC SECTION ACROSS YUCAIPA BASIN feet thick in the deep central part of the valley, and may even exceed 2000 feet in its deepest part. A thickness of Quaternary alluvium as great as this could have accumulated only with the aid of subsidence of the surface, since the alluvial fill extends to more than 1000 feet below sea level.

Upper Santa Ana Valley.

The alluvial plain of San Gabriel Valley narrows to a width of about two miles at the east end of the valley in the vicinity of La Verne, and then widens eastward into Upper Santa Ana Valley. The greatest length of this valley is about 40 miles from west to east, and its width nearly 20 miles in the western part, narrowing to a point at the eastern end. The irregular bedrock floor of the valley is covered to depths exceeding 1000 feet with alluvial debris from the granitic and metamorphic rocks of the high San Gabriel and San Bernardino ranges. There is comparatively little alluvial fill from other sources and what there is, is confined almost entirely to a fringe along the south margin of the valley. In the region around Corona the alluvium has been derived from the Santa Ana Mountains.

The greater part of Upper Santa Ana Valley is covered by Recent undissected alluvium, but around the margins and occasionally at considerable distances from the mountains dissected remnants of higher deposition-surfaces with their characteristic reddish soil surfaces occur. These older alluvial surfaces are most extensively developed along the south margin of the valley. The Santa Ana River, below the San Jacinto fault at San Bernardino, has cut down through the Older alluvium and flows on a narrow flood plain incised between banks 50 to 100 feet high. North of the river the older dissected alluvial surface dips downward toward the north and is buried by Recent deposits from the San Gabriel Mountains. South of Santa Ana River there is very little debris being deposited and consequently the old dissected alluvial surface is practically intact in that area except where the Recent washes are incised into it.

The peculiar position of Santa Ana River, incised as it is, into Older alluvium and lying south of the present limit of active accumulation of debris from the high San Gabriel Mountains, strongly suggests Recent subsidence of the central part of the valley. Apparently in this manner alluviation has been prevented from reaching the river and in consequence this stream has cut into its surface of former deposition, fixing its course between alluvial banks (see Plate III, Fig. A).

Local uplift of the valley floor has caused dissection of the alluvium at several places and remnants of the older alluvial surfaces stand as mesas or low hills above the present level of deposition. Indian Hill near Claremont and Red Hill near Upland have been both produced in this manner.

The surface of Lytle Cone along the southwest side of Lytle Wash stands well above the wash throughout most of its length, the difference in elevation exceeding 50 feet in places. Northeast of the wash there is no corresponding higher surface. Apparently the cone surface southwest of the Wash has been uplifted, and the uplift has taken place so recently that dissection has scarcely begun on the uplifted area, and its surface has not yet developed the red clayey soil characteristic of older alluvial surfaces.

The Yucaipa-Beaumont Area.

Southeast of the Upper Santa Ana Valley proper there is an extensive deeply dissected and somewhat deformed old red alluvial plain in the Yucaipa-Beaumont area. This old surface is several hundred feet above the level of Upper Santa Ana Valley, and has apparently been uplifted and warped. The alluvium beneath this plain overlies a folded series of alluvial beds of probable Lower Pleistocene or Upper Pliocene age. A diagrammatic structure section across Yucaipa Basin is shown in Plate III, Fig. B. The folded series outcrops along the south and west edge of the plain. These sedimentary hills that rise around the southwest margin are in the main separated from the old alluvial plain by San Timoteo Canyon that heads in the vicinity of Beaumont and runs northwesterly about 16 miles, emptying into Upper Santa Ana Valley near Redlands. The Recent washes drain southwesterly across the plain into which they are incised, cutting into the folded series beneath the Older alluvium at its southwest margin, and empty into San Timoteo Canyon. The only area in which Recent alluvium is of any importance is at Yucaipa, where there is a Recent alluvial valley about one mile wide and two miles long whose floor is about 50 feet below the level of the old alluvial plain.

THE HIGH MOUNTAINS

The highland regions of the South Coastal Basin include parts of three mountain ranges; namely, the San Gabriel, San Bernardino and Santa Ana mountains. The San Gabriel and San Bernardino ranges form an east-west mountain chain, broken only by Cajon Pass, which runs along the entire north and northeast margins of the South Coastal Basin. The north end of the Santa Ana Mountains lies within the South Coastal Basin, forming the southeast margin of the Coastal Plain and the southwest margin of Upper Santa Ana Valley. The eastern end of the Santa Monica Mountains, the Verdugo Mountains and other low mountains are considered to be a part of the intermediate belt of low mountains and hills that break up the alluvial plains into separate units.

San Gabriel Mountains.

The San Gabriel Mountains are a series of fault blocks that have been thrust up during Pleistocene and Recent time to their present position from a region of rather low relief. The entire southern portion of these mountains lies within the South Coastal Basin. The south front of the mountains forms the north margin of eastern San Fernando, San Gabriel and Upper Santa Ana valleys west of Cajon Pass. The mountain-front is a bold maturely dissected escarpment whose base forms an irregular but sharp line separating the alluvial plain from the mountain slopes. West of San Antonio Canyon near Claremont, and south of the east-west canyons of Tujunga and San Gabriel rivers, the mountain tops range in altitude from about 3000 feet to a little more than 6000 feet above sea level, and have a rather uniform crest-line. North and east of this area the mountains rise to elevations of 8000 to 10,000 feet above sea level, the highest point being Mt. San Antonio, the elevation of which is 10,080 feet. Sharp ridges and deep V-shaped canyons characterize the mountain topography, very few remnants of old summit regions of low relief being present.

The drainage systems of the San Gabriel Mountains are divisible into two groups: (1) the major streams that drain through deep canyons from far back in the range, and (2) the minor streams which drain the steep mountain fronts between the major canyon mouths. The major stream pattern probably existed before the mountains were uplifted, and carved out the deep canyons through which the streams flow, as the mountains rose. The minor stream systems appear to be related directly to uplift of the mountains, having formed on the scarps produced by the uplift. The major streams have deposited the greater part of the alluvial debris and also supply the greater part of the run-off from the mountains.

San Bernardino Mountains.

The San Bernardino Mountains form a range similar in origin and size to the San Gabriel Mountains. They are a little more than 50 miles long in an east-west direction, and widen from a point at the summit of Cajon Pass to nearly 30 miles near their east end. The western part of these mountains has a remarkably even crest-line which forms the drainage divide between the Mojave Desert and the South Coastal Basin. Beginning near the summit of Cajon Pass in the west, at an elevation of about 5000 feet, the unbroken crest rises gradually toward the southeast for 25 miles to the Santa Ana River drainage area, where it reaches an elevation of a little more than 7500 feet. Here it is cut through by the V-shaped Bear Creek Canyon, 3000 feet deep, that drains the northeast interior (Bear Valley region) of the range, emptying into Santa Ana River. East of Bear Creek, the same ridge, which is no longer the drainage divide, continues to rise for a distance of 12 miles, culminating in Sugarloaf Mountain at an elevation of about 9500 feet.

Southeast of Santa Ana River the topography is rugged. The highest ridge in the range lies in this area, its highest point being San Gorgonio Peak, with an elevation of 11,485 feet.

The southwest front of the mountains faces Upper Santa Ana Valley in the vicinity of San Bernardino. This mountain face is the steep rugged fault scarp of the San Andreas fault that runs along its base, forming the sharp straight boundary between mountain-front and alluvial plain.

The summit region north of the crest-line mentioned above is a plateau, about 10 to 12 miles wide, that is ended abruptly along the north side by the steep scarp that forms the north front of the range. The relief in this plateau area is moderate, the mountain tops generally rising less than 1500 feet above the valley bottoms. The western part drains northward into the Mojave River, and the eastern part south into Santa Ana River.

This broad upland summit region is the somewhat modified old surface that existed before the range was uplifted, and forms a sharp contrast with the steep youthful topography that has been produced on either side of the range by uplift of the mountain block.

Santa Ana Mountains.

The Santa Ana mountain range is a fault block uplifted on the northeast side along the Elsinore fault zone, and tilted southwesterly toward the Coastal Plain. The rather uneven crest lies near the northeast side of the range. It rises southeasterly from the Santa Ana River and culminates in Santiago Peak (elev. 5680 feet) at the south edge of the South Coastal Basin. Northeast of the divide the mountain-front is steep, and drained by short steep-gradient streams that run into Temescal Wash at its base. Southwest of the divide long ridges slope westerly toward the Coastal Plain. Santiago Creek is the principal stream, and it drains practically all of the southwest slope of the mountains within the South Coastal Basin.

These mountains, like the San Gabriels and San Bernardinos, have been uplifted during the Pleistocene and Recent geologic periods. Their northwest extension forms the intermediate belt of hills between the Coastal Plain and the inland plains.

GEOLOGIC SKETCH

Considered in its relation to groundwater, the geology falls into two natural divisions; namely (1) geology of the pervious formations which form the groundwater reservoirs; and (2) geology of the less pervious formations which enclose the groundwater reservoirs. For convenience the first division is termed the **Water-bearing series,** and the second, the **Nonwater-bearing series.**

The Nonwater-bearing series consists of a Basement Complex made up of crystalline metamorphic and igneous rocks of pre-Cretaceous age, and a more or less indurated series of complexly folded and faulted sediments of Cretaceous, Tertiary, and early Quaternary age that in places covers the Basement Complex. These two groups of rocks in the main make up the hills and mountains of the South Coastal Basin and form the floors beneath the valley fill.

NATURE OF THE NONWATER-BEARING SERIES

The geologic history of the Nonwater-bearing series is not simple but the principal events which have led to the formation of structural ground-water basins in it are outlined briefly.

The Basement Complex is a coarsely crystalline mass composed of metamorphic rocks (schists, slates, gneisses, quartzites, etc.) and deep seated intrusive rocks (granites, diorites, etc.). It was formed at great depth and under conditions of great heat and pressure. Deeply buried ancient sediments were transformed into schists, gneisses, etc., by recrystallization and were invaded from below by magmatic intrusions which upon cooling crystallized into granitic and dioritic rocks.

Subsequently a long period of erosion removed the several thousand feet of material which covered the Basement Complex, and these crystalline rocks thus became the land surface. In Upper Cretaceous time a long and complex record of deposition upon the Basement Complex began, which, interrupted by periods of deformation and local erosion, has continued through the Tertiary period to the present time, during which enormous thicknesses of shales, sandstones and conglomerates have accumulated. Throughout the post-Eocene deposition, the basins of accumulation have been local and more or less surrounded by high areas which shed sediments. During later Tertiary (Upper Miocene and Pliocene) and early Quaternary time, there appears to have been a large basin of deposition occupying most of the area of the South Coastal Basin. Its northern and eastern margin extended in a semicircle from the western part of the San Gabriel Mountains southeasterly along the base of the mountains to the vicinity of La Verne and Claremont, then swung southerly through what is now the western part of the Upper Santa Ana Valley, crossed the north end of the present Santa Ana Mountains and ran southerly along the western slopes of these mountains into San Diego County. Most of the Santa Monica Mountains, the hills that separate San Gabriel Valley and Upper Santa Ana Valley from the Coastal Plain, and at least a part of the San Joaquin Hills southwest of Santa Ana were a part of this basin. The later Tertiary and early Quaternary sediments deposited in this basin are nearly all marine. However, north and west of San Fernando the Saugus formation (Pliocene-Pleistocene) is at least in part continental, and at several other localities near the basin margin, conglomerates have the aspect of continental deposits.

Although several periods of deformation occurred in the Tertiary during which the sediments were folded and in part eroded away, the late Tertiary basin remained more or less a unit throughout the Pliocene and well into Pleistocene time.

In mid-Pleistocene time a period of deformation which began earlier became intense, and has continued up to the present. The earth's crust was broken into great fault blocks, some of which were thrust up by compressive forces to form mountain ranges. The miles thick series of Tertiary and early Quaternary sediments yielded to the compressive forces by folding, and to a lesser degree by faulting. Thus the mountain ranges of today were formed and the Tertiary basin was broken up by folding and faulting into the several local basins of deposition which form the valleys and plains of the South Coastal Basin.

Although practically all of the groundwater produced commercially comes from the alluvial and later marine sediments of the Water-bearing series that fill the later Quaternary structural basins, more or less water is contained in all the relatively impervious formations of the Nonwater-bearing series which surround and underlie the basins. Water in these formations is used for domestic purposes, and locally for small irrigation enterprises. The water-bearing properties of these older relatively poor water producing formations is, therefore, discussed briefly.

There are many gravelly and sandy facies in the Nonwater-bearing series that are pervious, and from which in some cases individual wells produce considerable water. However, these sediments are generally so situated topographically or structurally that they are separated from the productive basins, and furthermore their structure is usually so complex (cut by many faults) that movement of ground-

PLATE IV

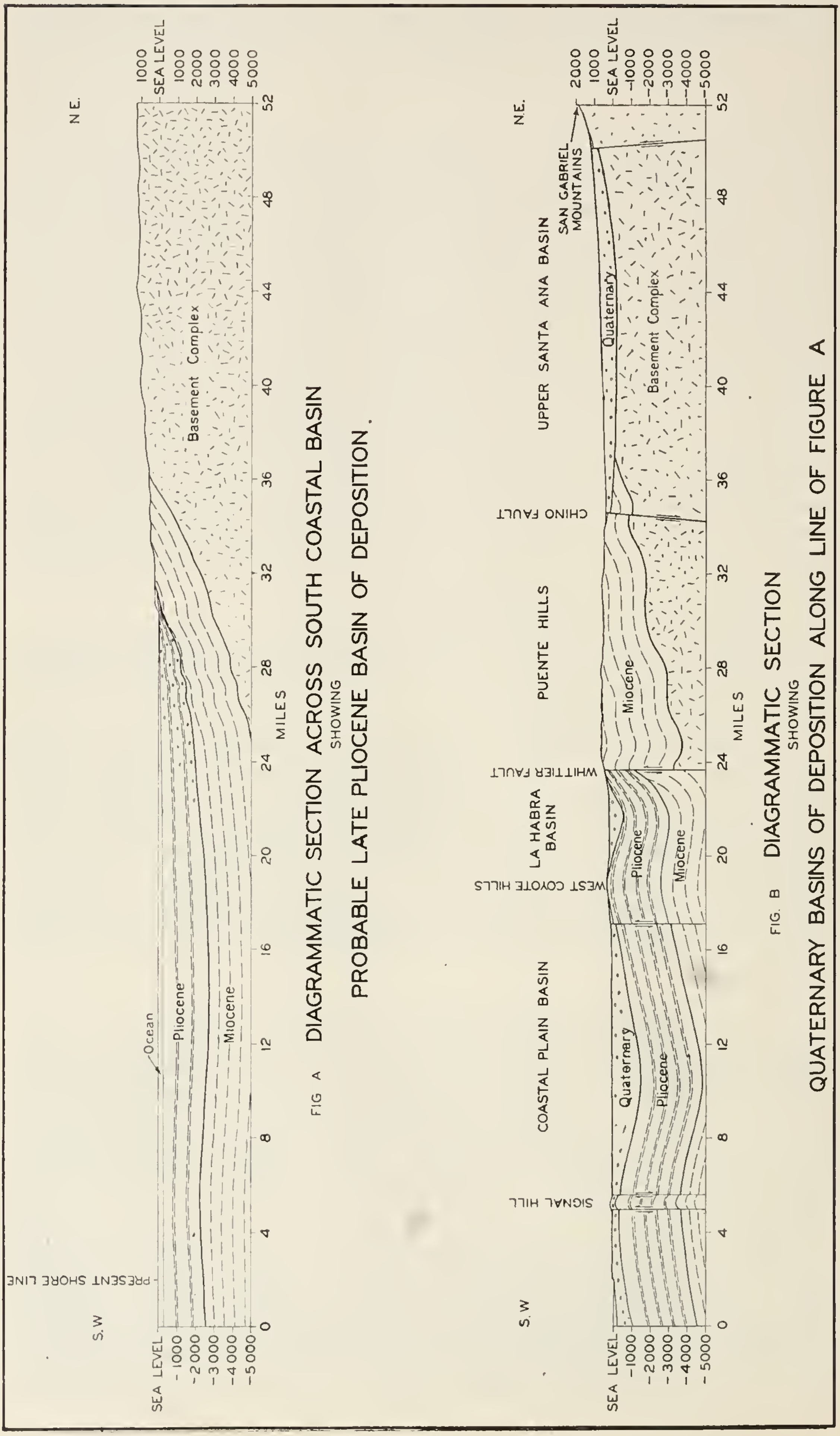


FIG. A DIAGRAMMATIC SECTION ACROSS SOUTH COASTAL BASIN SHOWING PROBABLE LATE PLIOCENE BASIN OF DEPOSITION.

FIG. B DIAGRAMMATIC SECTION SHOWING QUATERNARY BASINS OF DEPOSITION ALONG LINE OF FIGURE A water within the formations themselves is restricted. The groundwater level in the Nonwater-bearing series, even where pervious beds occur, stands near or at the surface in the principal streambeds and therefore any excess not utilized by transpiration or evaporation flows as surface water into the valleys. Where underflow does occur from pervious beds into the groundwater basins it is local and relatively constant.

In most areas the Nonwater-bearing series is too tight and cut by too many barriers to make possible the artificial withdrawal from it of water in any quantity. A large part of the water contained in it, especially in the deeper zones, is trapped connate water and is too high in dissolved salts to be used for irrigation or domestic purposes.

There are, no doubt, local areas in the Nonwater-bearing series from which groundwater supplies of good quality could be obtained by proper development, but such supplies would be neglible compared to those of the Quaternary groundwater basins.

NATURE OF THE WATER-BEARING SERIES

The later Quaternary structural basins, at first shallow, have sunk under the loads of debris poured into them by the streams of the rising mountain ranges, and thus have permitted the accumulation of pervious Upper Pleistocene and Recent gravels, sands, and clays to depths of 1000 to 2000 feet. Plate IV, Fig. A, is a diagrammatic section through the late Pliocene basin, and Plate IV, Fig. B, shows the same section as it is at present.

These natural groundwater reservoirs of the South Coastal Basin are thus great structural depressions of geologically recent origin, filled with unconsolidated marine or alluvial debris, the products of erosion following the great Pleistocene and Recent deformation.

Because these basins and their deposits are geologically recent and related both to the present topography and to the geologic structure, they have certain characteristic physical features not possessed by the older formations, which define them as the groundwater reservoirs which furnish about 90 per cent of the water recovered within the area of the South Coastal Basin. Briefly, these physical conditions are: (1) simple synclinal structural units; (2) low topographic position so that they receive the drainage from the surrounding areas; (3) undeformed and simply deformed pervious valley fill through which there is movement of groundwater as a body, permitting withdrawal and replenishment; (4) the existence of natural barriers which partly or entirely surround the basins.

From the geologic map in pocket it can be seen that certain folded Quaternary and Tertiary sediments adjacent to the valley fill are included with the Water-bearing series. These sediments are pervious facies of the Pliocene and Lower Pleistocene sediments which underlie the valley fill and come in direct contact with it. They thus form a part of the groundwater basins and their waters can be withdrawn by pumping or by drainage into the valley fill, and replenished by percolation.

PLATE V

GENERALIZED STRATIGRAPHY OF SOUTH COASTAL BASIN

AGE		GEOLOGIC FORMATIONS		DESCRIPTION	THICKNESS IN FEET
QUATERNARY	RECENT	Alluvium.		Poorly sorted, unconsolidated sand, gravel and clay. Generally undissected and undeformed. Sand dune deposits along west coast.	0 -100
				Local unconformity	
QUATERNARY	UPPER PLEISTOCENE	**OLDER ALLUVIUM** (San Dimas formation), **PALOS VERDES** marine series and possibly upper beds of San Pedro (restricted) series in central part of basin.		Marine and alluvial terrace deposits around basin margins. Thick series of poorly consolidated marine and continental clays, sands and gravels in central parts of basins. Characteristic red or brown weathered surface. Deformation generally slight at surface, but increases with depth.	0-2000
				Local unconformity	
QUATERNARY	LOWER PLEISTOCENE	Western portion: **SAUGUS** formation (locally called La Habra conglomerate), includes San Pedro, Timms Point and Lomita beds exposed along northeast margin of San Pedro Hills. Eastern portion: **SAN TIMOTEO** continental and lacustrine beds.		Widely distributed and locally variable continental and marine poorly consolidated folded conglomerates, sands, silts and clays. Beds are principally silts and clays beneath greater part of Coastal Plain.	500-2000
				Local unconformity	
TERTIARY	UPPER PLIOCENE	**PICO** formation (upper and middle Pliocene). Possibly includes lower portion of San Timoteo Series.		Blue sandy shale and siltstone with sandstone and conglomerate lenses. Principally marine.	1500-3000
TERTIARY	LOWER PLIOCENE	**REPETTO** formation. Possibly also sandstone beds of uncertain age in Cajon Pass region. Santa Ana sandstone.		Blue and brown siltstone, sandy shale and sandstone, with local conglomerate members.	2500-5000
				Local unconformity	
TERTIARY	UPPER MIOCENE	**MODELO** and **PUENTE** formations. Sandstones of Cajon Pass and Santa Ana sandstone.		Alternating marine shale and sandstone members. Thin-bedded cherty siliceous shale, diatomaceous shale and diatomite varying to clayey and sandy facies. Thick coarse massive arkosic sandstone and conglomerate with interbedded fine sandstones and shale. Sharp local variations. Associated with intrusive and extrusive basalt and other igneous rocks.	4000-7000
				Local unconformity	
TERTIARY	LOWER MIOCENE	**TOPANGA** formation.		Massive gray and brown marine sandstones and conglomerates with gray clay shales. Abundance of intrusive and extrusive basaltic rocks.	700-7500
				Disconformity	
TERTIARY	LOWER MIOCENE / OLIGOCENE	**VAQUEROS-SESPE** formations. Possibly also potato sandstone in eastern portion.		Coarse, brown, marine sandstones, red conglomerates and sandstones with red and green clay shales.	3000-4000
				Unconformity	
TERTIARY	UPPER EOCENE	**TEJON** formation.		Coarse, ouff, arkosic, marine sandstone with clay shales and basal conglomerate.	500-600
				Unconformity	
TERTIARY	MIDDLE EOCENE	**MEGANOS** formation.		Soft muddy shale and fine-grained, gray sandstone. Marine.	600-900
				Unconformity	
TERTIARY	LOWER EOCENE	**MARTINEZ** formation.		Light brown and grey, hard, marine sandstone with interbedded sandy shales and conglomerates	250-900
				Unconformity	
MESOZOIC	UPPER CRETACEOUS	**CHICO** formation.		Marine, hard sandstone and conglomerate with dark, clayey shales.	8000
MESOZOIC	UPPER CRETACEOUS	**TRABUCO** formation.		Continental, red, clayey conglomerate and sandstone.	300-750
				Unconformity	
MESOZOIC	JURASSIC		BASEMENT COMPLEX	Granitic intrusives.	
MESOZOIC	TRIASSIC	**SANTA MONICA** slate in Santa Monica Mountains.	BASEMENT COMPLEX	Black slates with schist facies.	5000-7000
PALEOZOIC	CARBONIFEROUS	**SARAGOSSA** quartzite.	BASEMENT COMPLEX	Massive white to buff quartzite with interbedded schist and limestone lenses.	
PALEOZOIC	CARBONIFEROUS	**FURNACE** limestone.	BASEMENT COMPLEX	White, massive to thin-bedded, dark gray crystalline limestone.	
AGE UNCERTAIN		Includes Pelona schist (possibly Pre-Cambrian).	BASEMENT COMPLEX	Metamorphic gneisses, schists etc., of San Gabriel and San Bernardino mountains.	

Compiled from XVI International Geological Congress Guidebook 15, 1932, and other sources.

ORIGIN OF THE PRESENT TOPOGRAPHY

Very few of the land forms in existence today originated in anything like their present form prior to Upper Pleistocene (late Quaternary) time. The oldest erosion surfaces in the region are the isolated upland surfaces of comparatively low relief that remain on the mountain ranges above the deep steep-walled canyons, and in the Perris Plain region south of Riverside. Even these (pre-later Quaternary) surfaces must in many cases have undergone great changes during the later Quaternary period, for soft sediments which filled the depressions before uplift of the mountains have since been partly or entirely removed by erosion, leaving escarpments and benches in the bedrock. Bear Valley and Holcomb Valley in the San Bernardino Mountains offer good examples of this sort of modification of the pre-Upper Pleistocene surfaces. Both of these valleys were at one time filled with alluvium to considerably higher levels than at present, as indicated by high alluvial and bedrock benches now hanging above the valley floors. Since uplift of the range, a large part of this pre-uplift alluvium has been removed, but enough remains to give evidence of the former surface. Similar conditions apparently existed on the Perris block south of Riverside.[1]

Except for these upland remnants, all the land surfaces have been formed during later Quaternary time. The intensive erosion which has accompanied uplift of the mountain blocks has greatly modified these mountains and the mature dissection represented by the V-shaped canyons and pointed ridges cut below the old upland surfaces has all been accomplished since their uplift began. Similarly the mature surfaces of the intermediate hills and low mountains are related directly to later Quaternary base levels of erosion, all remnants of older erosion surfaces having been removed from these areas.

STRATIGRAPHY

The older relatively impervious formations are considered to be nonwater-bearing in this report. They are divisible into two main groups: (1) the ancient metamorphic and igneous crystalline rocks of the Basement Complex; and (2) the Cretaceous and Tertiary indurated sedimentary series.

The stratigraphy of the Nonwater-bearing series of the South Coastal Basin is shown graphically in Plate V.

THE BASEMENT COMPLEX

The Basement Complex of this region has received less attention from geologists than the later sedimentary series, and although the rocks in certain areas have been described in detail, these areas so studied are scattered and the information so incomplete that age relationships and in some areas even rock types remain obscure. The nature and general distribution of the more important rock types are described, however.

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[1] Dudley, Paul H., Geology of a Portion of the Perris Block, Southern California. (Abstract) Geol. Soc. Am. Bull. Vol. 43, p. 223, 1932.

Ancient (Metamorphic) Banded Gneisses.

A series of well banded metamorphic gneisses occur in the San Gabriel Mountains, and together with the complex intrusive rocks which cut them form the main mass of the southern slopes of the mountains eastward from Dalton Canyon almost to Lytle Creek. West of Dalton Canyon these banded gneisses swing northerly into the heart of the range. Typically, they are alternating well-defined light and dark bands from a few inches to more than one foot wide. Locally the banding is thinner, and the rocks are practically schists. The light bands are generally quartz, or quartz and feldspar; the dark bands are largely biotite (black mica) and hornblende, sometimes dark green chlorite. Limestone and quartzite bands or lenses are common. Some of these attain thicknesses of hundreds of feet.

Dikes and larger intrusive masses of nearly every description cut the banded gneisses. Coarse-grained, light colored dikes of aplite, alaskite and granodiorite are common. Many fine-grained acid to basic "porphyry" dikes, probably of Tertiary age, cut the gneisses in the vicinity of San Gabriel Canyon and elsewhere.

Gneissic parting is not prominent in the fresh rocks and is generally confined to the mica or hornblende bands. These gneisses have a tendency to shear along planes of schistosity.

The banded gneisses are hard and tight where fresh and unfaulted, but over large areas they are sheared and closely fractured. They are cut by many small faults and by several large zones of faulting. The effects of this extensive shearing and fracturing are evident in the San Gabriel River canyon.

Metamorphic Sediments of the San Bernardino and San Gabriel Mountains.

In the San Bernardino Mountains there are remnants of old sandstones and limestones which have been recrystallized and intruded by the "granites." These formations occur within the South Coastal Basin only in its extreme northeast part, and are there represented by two formations, the Furnace limestone and the Saragossa quartzite. These formations have been described in detail by F. E. Vaughan,[1] and since their bearing upon the problems of groundwater in the South Coastal Basin is remote, only the most important features of their occurrence are discussed here.

Practically, there are only two areas of Furnace limestone within the South Coastal Basin. One forms Bertha Peak, on the north side of Big Bear Lake, the other lies on the north slope of Sugarloaf Mountain, a few miles southeast of Big Bear Lake. It varies from white coarsly crystalline (often dolomitic) massive, to fine-grained, thin banded, dark gray limestone. Fossils found in this formation fix its age as Paleozoic, probably Carboniferous[2] (Mississippian).

The limestone is compact but parts readily along bedding planes, which thus afford cracks along which groundwaters percolate. This limestone evidently has undergone erosion in an arid climate, for

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[1] Vaughan, F. E., Geology of the San Bernardino Mountains north of San-Gorgonio Pass, Univ. Calif. Pub. Bull. Dept. Geol. Sci., Vol. 13, pp. 352–363, 1922.

[2] Woodford, A. O., and Harris, T. F., Geology of Black Hawk Canyon, San Bernardino County, California, Univ. Calif. Pub. Bull. Dept. Geol. Sci., Vol. 17, p. 270, 1928.

solution openings (caverns) common in many limestones are very rare in the Furnace limestone.

The Saragossa quartzite overlies the Furnace limestone and also lies almost entirely outside the South Coastal Basin. It extends westward into the Basin only at a few places in the vicinity of Big Bear Valley. It is characteristically hard, brittle, white to pink, iron stained and massive. Locally the quartzite becomes schistose, and in places includes biotite schist.

Both quartzites and limestones are present in the San Gabriel Mountains. They occur in scattered outcrops, principally in the eastern part, between San Antonio Canyon and Lytle Creek.

Massive Gneisses and Granitic (Igneous) Rocks.

Coarsely crystalline massive rocks comprise a larger part of the Basement Complex and are more generally distributed than any of the more schistose types.

In this group are included: (1) old intrusive dioritic and granitic rocks (principally in the San Gabriel Mountains) which are probably of pre-Cambrian or Paleozoic age, and which have themselves been more or less metamorphosed and intruded by later "granites"; and (2) the later granitic intrusives, probably of Mesozoic age, which are mainly granites and granodiorites, but also include more basic types such as diorite and gabbro. Locally these later "granites" are strongly gneissic, the gneissoid texture apparently being due to marginal flow structure rather than to recrystallization. Pegmatite and aplite dikes are common in the granitic rocks.

The massive old metamorphic gneisses occur most abundantly in the San Gabriel Mountains. They are intimately associated with the banded gneisses and are intruded by the later "granites." They differ from the banded gneisses, in that the dark and light minerals are not as well segregated into bands.

The later (Mesozoic) granitic intrusive rocks probably were parts of the great pre-Cretaceous batholiths which produced the extensive "granites" of the Sierra Nevada and the Peninsular ranges of California. These rocks occur in all the mountain ranges of the South Coastal Basin. In the San Gabriel and Santa Ana Mountains, they are intricately associated with the older rocks that they intrude, and no single mass forms a large part of either range. Granodiorite (and some granite) covers the greater part of the San Bernardino Mountains within the South Coastal Basin, and in the region around Riverside and westerly to Corona it is almost the only rock found in the Basement Complex.

PRE-OLIGOCENE SEDIMENTS

The oldest sediments deposited on the Basement Complex in the South Coastal Basin are Upper Cretaceous (Chico) and Eocene hard conglomerates and sandstones containing hard clayey shale and limestone members. These older sediments occur in three areas; namely, in the Santa Monica Mountains northwest of Santa Monica; in the Simi Hills at the western edge of the San Fernando Valley; and in the Santa Ana Mountains, flanking the west, north and northeast sides of the range.

Chico Formation.

Chico beds of the Simi Hills section form the northwest margin of San Fernando Basin in the vicinity of Chatsworth. The exposed part of this section as described by Kew[1] consists of about 500 feet of shale, sandy shale, and calcareous sandstone, overlain by a heavy-bedded sandstone series about 5500 feet thick. The sandstones are interbedded with thin gray micaceous shale beds but the section is predominantly medium to coarse-grained, well-cemented, brown sandstone. This formation forms a broad westward plunging syncline with its southwest flank against San Fernando Basin.

In the Santa Monica Mountains, Hoots[2] recognized two members of the Chico formation. Lying directly upon the Santa Monica slate is a soft friable red conglomerate and sandstone. It is overlain by hard greenish-gray conglomerate containing thin beds of shale, sandstone and limestone and thick beds of light gray conglomeratic sandstone. Hoots gives the exposed thickness of these members as approximately 750 feet for the lower and 2500 feet for the upper. These beds outcrop over a comparatively small area near the western margin of the South Coastal Basin. On the southern side of the mountains they were not differentiated from Martinez (Eocene) beds but appear to be at least 8000 feet thick.

Chico beds flank both the southwest and the northeast sides of the Santa Ana Mountains, overlying unconformably the Basement Complex. On the southwest side, the base of the Cretaceous section is a massive, rather poorly cemented, reddish conglomerate derived from the adjacent Basement Complex. This formation, having a thickness of 200 or 300 feet was named Trabuco formation by Packard.[3]

The Trabuco is overlain conformably by a thick section of well-cemented conglomerates, sandstones and shales containing Chico fossils. Since there does not appear to have been a period of erosion between the deposition of Trabuco beds and the overlying known Chico beds it seems probable that the Trabuco is also of Chico age.

The Chico formation comprises a belt several miles wide along the southwest side of the mountains flanking the Basement Complex, dipping generally at a moderate angle southwesterly toward the Coastal Plain and overlain by a thick section of Tertiary sediments. On the northeast side of the mountains, similar steep-dipping beds flank the Basement Complex.

Eocene Formations.

Sediments of Eocene age occur within the South Coastal Basin only in a few isolated areas and are not an important part of the Tertiary sediments. They resemble the Chico in some respects but are less indurated. Coarse to fine sandstones and sandy shales predominate, but conglomerate members are common.

In the Santa Ana Mountains two Eocene formations are represented. The lower, Martinez, overlies unconformably the Chico forma-

[1] Kew, W. S. W., Geology and Oil Resources of a Part of Los Angeles and Ventura Counties, California. U. S. Geological Survey Bull. 753, pp. 11–13, 1924.

[2] Hoots, H. W., Geology of the Eastern Part of the Santa Monica Mountains, Los Angeles County, California. U. S. Geological Survey Prof. Paper 165-C, p. 90, 1931.

[3] Packard, E. L., Faunal Studies in the Cretaceous of the Santa Ana Mountains, Univ. of Calif. Dept. Geology Bull., Vol. 9, pp. 140–141, 1916.

tion and is overlain unconformably by the Tejon. As described by English,[4] the Martinez is principally soft brown fine sandstone with lesser amounts of coarser sandstone and some conglomerate near the base. The overlying Tejon formation is typically a white to yellow coarse quartzose sandstone containing conglomeratic beds.

Along the northeast base of the Santa Ana Mountains from Corona to Lake Elsinore, isolated areas of Martinez occur. Here they are represented by a soft coarse white quartzose sandstone, sandy and silty shales, and lignitic clays.

Marine faunas typical of the Martinez and Tejon have been described from the respective formations by Dickerson.[5] Non-fossiliferous occurrences were correlated by lithology.

In the Santa Monica Mountains hard massive Martinez conglomerates and sandstones overlie similar Chico rocks. In the Simi Hills the thick Martinez section that overlies the Chico formation is almost entirely outside the South Coastal Basin.

OLIGOCENE (?) AND LOWER MIOCENE FORMATIONS

Lower Miocene sediments are more generally distributed about the South Coastal Basin and come more directly into contact with the water-producing series of the ground water basins than any of the older sedimentary formations.

The Lower Miocene of this region is characterized by coarse indurated conglomerates and massive yellowish-brown pebbly arkosic sandstones. In the Lower Miocene, Tertiary volcanic materials make their first appearance. Pebbles of basalt, andesite and various other types of volcanics occur in the conglomerates, and in places lava flows, tuffs and agglomerates are interbedded with the sediments. Variations in lithology are sharp and local. Thick sections of massive conglomerates and sandstones pass laterally into thin bedded sandstones and shales within very short distances. Evidently the Lower Miocene was a period of mountain making accompanied by vulcanism in this region. Sharp relief and local deep depressions are indicated. The conglomerates are in many places continental but pass laterally into marine strata. In general, the sediments are compact and rather well-cemented.

The lowermost (continental) beds of this series may be of Sespe (Oligocene) age, but appear to be conformable with the overlying known Miocene strata.

Sespe (?) and Vaqueros Formations.

In the Santa Ana Mountains there is a section of about 3000 feet of soft, reddish sandstone and clay with lenses of conglomerate overlying the Tejon unconformably, which contains marine Vaqueros fossils only in the upper few hundred feet. English, on the basis of its stratigraphic position, has considered the greater part of this formation to be Sespe (Oligocene), but there is no fossil evidence to substantiate this correlation. The absence of massive conglomeratic

[4] English, W. A., Geology and Oil Resources of the Puente Hills Region, Southern California, U. S. Geological Survey Bull. 768, pp. 19–20, 1926.

[5] Dickerson, R. E., The Martinez and Tejon and Associated Formations of the Santa Ana Mountains. Univ. Calif. Dept. Geology Bull., Vol. 8, pp. 257–270, 1914.

sandstones and conglomerates is striking in these beds when compared with Lower Miocene sediments elsewhere in the basin. It may well be that this series of red beds is in part pre-Miocene.[1]

The Vaqueros-Sespe (?) beds outcrop in several places on the western flank of the Santa Ana Mountains. Only in a small area along the edge of the foothills and at the mouth of Santiago Creek do they form a part of the margin of the alluvial basin. They outcrop also along the east side of the San Joaquin Hills west of Irvine where a thick section of massive arkosic yellowish-brown sandstone is exposed.

Hoots has described a series of red sandstones and conglomerates in the Santa Monica Mountains at the west edge of the South Coastal Basin, and almost entirely outside it. These red beds underlie with apparent conformity Topanga beds.[2]

Topanga Formation.

The Topanga (Temblor) formation is similar in lithology to the Vaqueros but is much more widespread throughout the South Coastal Basin.

It consists in the main of massive hard conglomeratic sandstones and conglomerates with lesser amounts of interbedded shale. Volcanic flows, tuffs and breccias occur throughout the Topanga, and are associated with basic igneous dikes. In the main the volcanics are basic, basalt being the most common type.

The Topanga overlies the Vaqueros with apparent conformity and is overlain unconformably by the Modelo formation in the Santa Monica Mountains. It has a distinctive marine fauna, but locally the conglomeratic facies probably are continental. Near the eastern end of the Santa Monica Mountains and eastward to Pasadena there is a belt of Topanga overlying the Basement Complex. Hoots[3] describes it as follows:

> "The Topanga formation, although far from uniform in detail features, is as a whole of fairly consistent character throughout its extent in the eastern part of the Santa Monica Mountains. The formation consists essentially of a thick, steeply dipping series of sandstone, conglomerate, and shale, together with a large amount of intrusive and extrusive basalt of Topanga age. (See pp. 95–96.) In most areas massive conglomeratic sandstone occurs in the lower part of the formation, associated with the basalt; this is generally overlain by a considerable thickness of thin-bedded shale and sandstone, locally intercalated with more massive beds of sandstone. In some areas the highest exposed part of the formation, stratigraphically above the thin-bedded shale and sandstone, is characterized by another series of massive sandstone with shale."

Eastward from the Santa Monica Mountains massive conglomeratic sandstones and conglomerates predominate. The materials are coarsest near the Eaglerock fault (Plate A) which forms the northern contact with Basement Complex, and rapidly become finer to the south. Marine shales and fine sandstones appear within one-half mile of the fault. The pebbles and cobbles are Basement Complex types and evidently the source of the Topanga sediments of this area was the crystalline terrain immediately to the north. Between the Los Angeles River and Pasadena, lava flows are absent from the Topanga. Hard conglomerates and sandstones interbedded with lava flows, of possible Topanga age, outcrop along the base of the San Gabriel Mountains near Azusa, where they are faulted down against Basement Complex.

[1] English, W. A., *op. cit.* p. 23.
[2] Hoots, H. W., *op. cit.*, pp. 93–94.
[3] *Op. cit.*, p. 94.

This formation underlies and bounds most of the southeast corner and outlet of the San Fernando Basin, and extends eastward as a wedge ending under the southwest corner of the Pasadena area between the Eaglerock and Raymond faults.

In the Santa Ana Mountains the Topanga formation is represented by a few hundred feet or less of fossiliferous sandstone that overlies disconformably the Vaqueros. The two are separable there only on the basis of fossils. The Topanga is present also in the San Joaquin Hills where a thick sandstone series is faulted down on the east against the Vaqueros.

UPPER MIOCENE FORMATIONS

The Upper Miocene period in this area was characterized by the accumulation of immense thicknesses of laminated siliceous, diatomaceous and cherty shales with local usually lenticular sandstone and conglomerate facies. Lateral variations from shale to sandstone and conglomerate are sharp and the coarser members often attain considerable thickness. Some of these coarser members are of sufficient size to be shown separately on the geologic map, and in the Puente and San Jose hills these coarse facies form a considerable part of the section.

There are two principal Upper Miocene formations represented in the area: The Modelo, in the San Fernando Valley, Santa Monica Mountains and San Pedro Hills; the Puente, in the hills and mountains around the Coastal Plain southeast of Los Angeles. These formations are, in large part, equivalent in age to the Monterey shale, but this term has not generally been applied in this region.

Relatively small areas of Upper Miocene sandstones and conglomerates occur in Cajon Pass and at several places along the southwest base of the San Bernardino Mountains.

The lower member of the Modelo shale in the Santa Monica Mountains and the lower shale of the Puente formation in the Santa Ana Mountains both overlie the Topanga unconformably. In the San Pedro Hills there are several thousand feet of lower Modelo beds stratigraphically below the lower Modelo member in the Santa Monica Mountains and stratigraphically above the Topanga.[1] Both the upper Modelo and the upper Puente members are overlain by Lower Pliocene (Repetto) beds. Evidently these two Upper Miocene formations are, at least in large part, equivalent stratigraphically. In general, their lithology is very similar, but the individual members are largely facies differences due to geographic location, and since correlation of the various members is not important to the occurrence of groundwater, no attempt was made to correlate the two formations.

Modelo Formation.

According to Hoots[2] the Modelo of the Santa Monica Mountains consists of two conformable members. The lower member has a maximum thickness of 2750 feet as measured by Hoots, and the upper member a thickness of 2300 feet. He describes the formation briefly as follows:

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[1] Smith, Hampton, Oral communication, 1933.
[2] Hoots, H. W., *op. cit.*, pp. 102–103.

"In most of the area covered by this formation the exposed thickness of the lower member is greater than that of the upper and consists of thin-bedded shale (pl. 24, A, B) alternating with more massive units of coarse gray and brown sandstone (pl. 22, A) the largest of which have been individually mapped on Plate 16. Much of the shale is hard, platy, and opaline and is rich in the calcareous and siliceous remains of microscopic marine animals and plants, such as Foraminifera, Radiolaria and diatoms. Ordinary, soft, earthy shale is also very common in this lower member. The upper member throughout most of its area of exposure, consists of soft white punky diatomaceous shale (pl. 25, C) and is in striking contrast to all portions of the lower member as well as all other stratigraphic units in the eastern part of the Santa Monica Mountains."

The upper Modelo shale skirts the western end of San Fernando Valley, lying in the syncline northwest of Calabasas. It underlies the alluvium of most of the south and west parts of San Fernando Valley, and passes beneath Pico (Pliocene) beds which form the floor of the alluvium in the northwestern part of the valley. Sandstone members in the upper shale as mapped by Hoots are shown on the geologic map.

Massive conglomerates and sandstones, assigned to the Modelo by Kew,[3] under Tujunga Valley (at the northeast edge of San Fernando Valley) and form the adjacent hills on both sides of the valley.

In the San Pedro Hills, three members of the Modelo formation have been recognized. According to Hampton Smith,[4] the upper member, a mudrock, is equivalent in age to the upper shale member of the Santa Monica Mountains. The middle member, a diatomite, is approximately equivalent stratigraphically to the lower member of the Modelo in the Santa Monica Mountains, or Middle Modelo in age, and the lower member which is undifferentiated siliceous and silty shale with interbedded sandstones is Lower Modelo and may include locally beds of the uppermost Topanga.

Puente Formation.

Following general usage, the Upper Miocene beds from the Los Angeles region southeastward through the Puente Hills, in the Santa Ana Mountains and San Joaquin Hills, are shown on the geologic map as Puente formation.

This formation has the greatest areal extent of any of the Tertiary sediments in the South Coastal Basin and comprises most of the Puente and San Jose hills. The Puente formation was named and first described by Eldridge[5] who divided it into three members, the lower shale, the middle sandstone and the upper shale.

The formation was later described in more detail by English.[6]

The lower shale outcrops north of the Whittier fault at various points along the southwest side of the Puente Hills, near Santiago Creek in the Santa Ana Mountains. It consists of laminated white siliceous shales, clayey and silty shales and fine arkosic sandstone beds. There are sandstone members of considerable thickness within the shale. English estimates the probable thickness of the shale at about 4000 feet. The lower shale southwest of Santiago Creek lies unconformably upon the Topanga, and at one place, directly upon the Vaqueros (Plate B).[7]

[3] Kew, W. S. W., *op. cit.*, pp. 65–66.
[4] Oral communication, 1933.
[5] Eldridge, G. H., The Puente Hills Oil District, Southern California. U. S. Geological Survey Bull. 309, p. 103, 1907.
[6] English, W. A., *op. cit.*, pp. 26–39.
[7] Burger, R. W., oral communication, 1933.

The middle sandstone of the Puente series outcrops over the greater part of the Puente Hills. As described by English,[8] this sandstone is yellow, poorly bedded, rather soft and made up largely of angular quartz grains. Well cores show it to be rather uniformly gray in unweathered sections. It is locally variable, and in the San Jose Hills is represented by an outcrop of 2000 feet or more of coarse, partly consolidated conglomerate. The Western Gulf Oil Company well, "Diamond Bar No. 1," drilled on the ridge east of Rodeo Canyon, penetrated fine to coarse arkosic sandstones and conglomerates, with very little shale to the depth of more than 6000 feet. In the main, the section was uniformly gray and well cemented. The lower part of this section may be a coarse facies equivalent to the lower shale exposed beneath the middle sandstone a few miles to the southwest (see section LMN, Plate D).

In the vicinity of Elysian Park in Los Angeles there outcrops a massive sandstone series which is probably the approximate age equivalent of the middle sandstone of the Puente Hills. Unfortunately no diagnostic fossils have been found in this member, but it appears to lie conformably beneath upper Puente shale, and is probably, at least in large part, middle Puente sandstone.

Arnold[9] has described this Elysian Park sandstone in part as

"at least 2000 feet of heavy-bedded, coarse gray rusty-arkose sandstone, interbedded at irregular intervals with dark colored earthy and siliceous shale. The sandstone beds vary in thickness from 1 to 12 feet. Some are uniformly hard throughout, while others are concretionary, * * * As a rule, however, the sandstone is soft and falls an easy prey to weathering agents, being much less resistant than the interbedded shale."

The upper Puente shale overlies conformably the middle sandstone in the eastern part of the Puente Hills and outcrops over most of the San Jose Hills. It is typically a thin-bedded hard siliceous shale, often highly diatomaceous and locally a diatomite. Calcareous and silty facies are not uncommon. Interbedded with the shale are medium to coarse-grained arkosic sandstones and massive conglomerate lenses. The coarser facies vary sharply, and conglomerates change to sandstones and shales within very short distances horizontally.

Other Upper Miocene Formations.

Noble[10] has described two Upper Miocene continental formations that outcrop along the northeast side of the San Andreas fault in Cajon Pass. The lower member is a hard massive sandstone and conglomerate. The upper member, about 1200 feet thick, consists of a series of poorly consolidated arkosic sands, gravels, and clays. Southeast along the San Andreas fault sandstones of probable Upper Miocene age outcrop.

[8] English, W. A. *op. cit.*, pp. 34–36.

[9] Arnold, Ralph, The Los Angeles Oil District, Southern California. U. S. Geological Survey Bull. 309, p. 146, 1907.

[10] Noble, L. F., Excursion to the San Andreas Fault, and Cajon Pass, Int. Geol. Congress Guidebook 15, pp. 12–13, 1932.

PLIOCENE AND LOWER PLEISTOCENE SEDIMENTS

Fernando Group.

By the beginning of Pliocene time the deposition of siliceous shales, so characteristic of the marine Upper Miocene deposits in the South Coastal Basin, had practically ceased. During Pliocene and Lower Pleistocene time, a thick series of blue and brown silty shales, silts, arkosic sands, and conglomerates were deposited over the entire western part of the South Coastal Basin, the aggregate probably reaching a maximum of more than 10,000 feet of sediments. This series is in the main marine, but locally near the margins gives way to considerable thicknesses of continental, partly consolidated, clays, sands and gravels. This thick series of Pliocene and Lower Pleistocene sediments comprises the Fernando group. Various subdivisions of this group have been recognized. Kew[1] divided the Fernando of the northwestern San Fernando Valley into an upper formation (Saugus) and a lower formation (Pico). The Saugus of this area is a continental conglomerate series, and the Pico, a marine sandstone series. Elsewhere in the basin, the Pico formation has been subdivided, and there is some disagreement among geologists concerning these subdivisions. R. D. Reed[2] has discussed this subject and summarized the various views briefly. He divides the Pliocene of this region into two formations, the Pico (upper), and the Repetto (lower).

The various age divisions of the Fernando group have been made on the basis of fossil evidence, and do not in most cases denote important changes in the character of sedimentation. Consequently they are not useful divisions for groundwater study, and therefore in this investigation the Fernando group has been subdivided roughly according to the water-bearing character of the sediments.

Two subdivisions have been made and are shown on the geologic map, Plates A, B, and C. The first, or **nonwater-bearing facies,** comprises the sediments which are predominantly shales, silts or fine sands, with comparatively little coarser material. The second, or **water-bearing facies,** comprises the sediments that are predominantly poorly consolidated sandy and gravelly deposits, so situated that they yield groundwater. The nonwater-bearing facies in general forms the lower member, where both are present.

The Fernando group, deposited originally over almost the entire area south of the San Gabriel Mountains and west of Upper Santa Ana Valley and the Santa Ana Mountains, has been eroded off the high areas, and outcrops now only around the margins of the Coastal Plain and alluvial basins. Its subsurface extent beneath the groundwater basins is much greater, however.

Fernando beds outcrop along the northern edge of San Fernando Valley, both facies being present. These beds occur in an east-west synclinorium between the San Gabriel Mountains and the central San Fernando Valley, the southern part being buried beneath valley fill. The alluvial fill of the southern portion of San Gabriel Valley is underlain by Fernando beds, which comprise a large part of the hills around the southern margin of the valley. Conglomerate members

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[1] Kew, W. S. W., *op. cit.*, pp. 69–70.

[2] Reed, R. D., Geology of California, Am. Assoc. Pet. Geologists, pp. 229–231. 1933.

overlie a silt section in this area and are difficult to distinguish from the alluvial fill where they underlie it.

A folded series of poorly consolidated gravels, sands and clays, outcrops along the edge of the alluvial fill of Upper Santa Ana Valley south of Chino. These beds are considered to be of probable Fernando age, on the basis of their poor consolidation and structural position. These conglomerates are faulted down by the Chino fault against upper Puente shale.

Although sediments of the Fernando group outcrop only intermittently in the hills that border the Coastal Plain, practically the entire later alluvial and marine fill of the plain is underlain by a very thick section of Fernando sediments. Except along the margin of the Coastal Plain the Fernando section is predominantly rather soft blue marine shale, silt and sand. Sand beds in the lower part of this formation have yielded the greater part of the petroleum produced from the oil fields around and on the Coastal Plain.

At Santa Fe Springs about 7000 feet of these beds were penetrated before reaching the Miocene contact. At Signal Hill the Fernando appears to be nearly 6000 feet thick. Elsewhere in the basin, comparable thicknesses are recorded. It is thinner, however, along the western border of the Coastal Plain, and where exposed along the eastern base of San Pedro Hills, has a thickness of only a few hundred feet.

The Fernando that outcrops in the Los Angeles area is principally a blue-gray shale and silt series with interbedded soft sandstones. Eastward in the Merced (Repetto) Hills some conglomerates are interbedded with the silts and sandstones. The beds become more conglomeratic to the east where they outcrop almost continuously, south of the Whittier fault, from the San Gabriel River Narrows to Santa Ana Canyon.

The conglomerate series in the upper Fernando that outcrops along the south margin of the hills east of Whittier is locally known as the La Habra conglomerate.[1] It has a thickness of about 400 feet in the vicinity of La Habra, but apparently thickens toward the west to a thickness of possibly 1000 feet, and is probably principally Lower Pleistocene, but may be in part Upper Pliocene. It overlies with apparent conformity silts and sandy shales with occasional conglomerate members.

These conglomerates underlie the Upper Pleistocene alluvium of the La Habra Basin (between the Puente Hills and the Santa Fe Springs-Coyote uplift), and form a part of the water-yielding series. They outcrop again to the south in the Coyote Hills. Coarsest east of Brea Canyon, the La Habra conglomerates become rapidly finer toward the west. Boulders one to two feet in diameter are not uncommon in the eastern part of the basin, but gravels encountered in wells west of La Habra toward Whittier are much finer, the coarsest materials being only a few inches in diameter. At Santa Fe Springs the section is largely sand and silt with occasional gravels, and is much finer even than that exposed on the north side of the basin near Whittier.

The La Habra conglomerate is composed, in large part, of granitic and Tertiary volcanic materials, with some sandstone and siliceous

[1] Bergen, H. M., Unpublished report on the geology of the Bastanchury Ranch.

shale pebbles. There is a concentration of white aplite and pegmatite pebbles throughout the conglomerate, and as Edwards[1] has pointed out, this indicates a primary source of granitic rocks cut by aplite and pegmatite dikes. Edwards concluded that the original source of these rocks was probably the Perris block to the east, the northern part of which is now buried beneath Upper Santa Ana Plain. An abundance of pegmatite dikes outcrop in the vicinity of Riverside.

The rapidity with which the conglomerates increase in coarseness toward the east side of La Habra Basin indicates a nearby source from short steep gradient streams. This fact, together with the presence of Tertiary volcanics, sandstone and siliceous shale pebbles and cobbles in the conglomerates strongly indicates that this series was derived locally from the Puente formation that outcrops over the Puente Hills immediately north and east of the Whittier fault.

Very little Fernando outcrops south of Santa Ana Canyon, but a thick conglomeratic section underlies the fill south and west of Olive. These conglomerate beds are exposed on the ridge east of Olive. Similar Fernando conglomerates outcrop locally in the hills east of Irvine.

Evidently deformation began along the eastern edge of the Tertiary basin in Pliocene time and had produced considerable relief by Lower Pleistocene time.

Along the coast, definite Fernando beds outcrop only in three areas. North of Santa Monica, Pliocene sands and silts are exposed in ravines south of the mountains and beneath the alluvium. Several hundred feet of Pliocene and Lower Pleistocene silts and sands outcrop in a narrow strip along the northeast base of the San Pedro Hills. Again at the south margin of the Coastal Plain (at the north end of the San Joaquin Hills) beneath the Costa Mesa marine terrace, a series of gently folded Fernando clays, silts and sands outcrop in the ravines and along the sea cliff.

Along the Beverly-Newport uplift Lower Pleistocene beds occur at comparatively shallow depths, and outcrop at the surface in at least one locality. West of this uplift they are not as deeply buried as they are to the east.

In the Baldwin Hills near Inglewood, upper Fernando massive silty and clayey shales are well exposed in the ravines of the northeast part of the hills and at one point near the base of the hills on the west side beneath Upper Pleistocene sands and gravels.[2] These beds are probably equivalent to the Timms Point zone, now generally considered to be Lower Pleistocene (see Plate V).

Elsewhere along the uplift the Timms Point zone has been recognized at depths of a few hundred feet, and at Seal Beach the base of the zone is only 500 feet below the surface.

In contrast to the Lower Pleistocene beneath the eastern part of the Coastal Plain, that exposed at the surface or encountered in water wells in the vicinity of the Beverly-Newport uplift and farther west is typically a fine facies and is considered to be a part of the Nonwater-bearing series. In this region the Lower Pleistocene is principally blue clay and silt, with some sand and rarely fine gravels.

[1] Edwards, E. C., Unpublished paper read before Am. Assoc. Pet. Geologists at Los Angeles, 1932.

[2] Robertson and Jensen, The Oil Age, Jan. 1926, pp. 35–45.

The relation of the Fernando group to the underlying Miocene is not one of simple unconformity. The difference in character of the deposits of these two periods indicates an important change in the physical conditions about the end of Miocene time. However, there does not appear to have been a period of general deformation and erosion between the two. for angular unconformities are local or lacking. Locally the lowermost Pliocene beds are missing, as Reed[2] points out to be the case at the San Pedro Hills outcrops. In the Los Angeles, Repetto and Puente Hills areas the exact contacts are determinable only on the basis of fossils. From this evidence and the presence of a very thick Pliocene section beneath the Coastal Plain, it seems probable that deposition was continuous through uppermost Miocene and probably all of Pliocene time in the deep central part of the basin, but locally around the margins a period of erosion intervened between upper Miocene and Pliocene deposition.

Upper Fernando time ended with the great mid-Pleistocene revolution which upheaved the present mountain ranges and produced the several basins of deposition in which sediments are now accumulating.

San Timoteo Beds.

In the eastern part of the South Coastal Basin, south of Redlands, a series of poorly consolidated continental gravels, sands and clays outcrop on the southwest limb of a broad syncline. They form a belt of bad lands running southeasterly from Upper Santa Ana Valley for nearly 20 miles. Frick[3] applied the name San Timoteo beds to this series, the name being derived from San Timoteo Canyon which runs northwesterly to Upper Santa Ana Valley through this belt of sediments. Frick considered these beds to be late Pliocene. The section exposed is several thousand feet thick and from its appearance and stratigraphic position, it seems possible that the upper beds of this series may well be Lower Pleistocene.

The San Timoteo beds are typical alluvial deposits, gently folded and eroded. The effects of weathering are prominent throughout. The beds are principally yellow decomposed sandy gravels, red or yellow sandy clays and red residual clays, with comparatively small amounts of calcite-cemented conglomerates and loose unweathered gray gravels. The materials are chiefly granitic, with lesser amounts of volcanic and metamorphic pebbles and cobbles.

The San Timoteo beds overlap the Basement Complex a short distance south of Beaumont, but an oil well about 1½ miles west of this contact, after penetrating 1100 feet of San Timoteo beds, entered marine shale, and at 1225 feet reached the Basement Complex. These marine beds probably belong to the Tertiary Salton Basin province.

Other Pliocene (?) or Lower Pleistocene (?) Formations.

The continental sandstones that outcrop in Cajon Pass northeast of the San Andreas fault and easterly in the San Bernardino Moun-

[2] Reed, R. D. *op. cit.*, pp. 228–229.
[3] Frick, C., Univ. Calif. Pub. Dept. Geology Bull. Vol. 12, pp. 283–288, 1921.

tains, according to Noble,[4] may in their upper part be Pliocene. However, since the greater part of this sandstone series is thought to be Miocene they are shown as such on the geologic map, Plate C.

The Santa Ana sandstone described by Vaughan[5] and located in the Upper Santa Ana River Canyon in the San Bernardino Mountains, was tentatively considered by him to be Pliocene. There is no direct evidence concerning the age of this formation, however.

LATE QUATERNARY (UPPER PLEISTOCENE AND RECENT) SEDIMENTS

The late Quaternary (Upper Pleistocene and Recent) sediments are those deposits that have accumulated in the local basins formed by the mid-Pleistocene revolution.

Although considerable work has been done by various investigators to unravel the complex history of Pleistocene deposition in this area, the exact geologic time at which the orogenic (mountain making) revolution began to affect the record of deposition is not clear.

In the chart (Plate V) showing the stratigraphy of the South Coastal Basin, the Upper Pleistocene includes the continental San Dimas formation, the sediments commonly referred to as ''earlier'' or ''older'' alluvium. The approximate marine equivalent is considered to be the coarse relatively shallow-water series that lies stratigraphically above the San Pedro formation.* This marine Upper Pleistocene series includes in its upper part the Palos Verdes sand which forms the lowest marine terrace at San Pedro.

There is a definite unconformity at the base of the Older alluvium (San Dimas formation) in all the inland basins. This alluvial series overlies rocks of pre-Cretaceous to Lower Pleistocene age, and wherever observed, well samples from immediately below the contact showed a weathered zone. These basins evidently were undergoing erosion before the mid-Pleistocene revolution.

In the Coastal Plain region the revolution did not produce a general erosional unconformity, but did cause a change in lithology from the blue clay and silt deposits to coarser deposits containing sands and gravels. Correlation of the mid-Pleistocene revolution with the faunal zones of the Pleistocene shown on the chart, although uncertain, was tentatively placed above the San Pedro zone and equivalent to the lower beds of the overlying gravelly series which has a warm water fauna similar to that of the type Palos Verdes sand. The type Palos Verdes at San Pedro is equivalent to only the upper beds of the gravelly warm water series; the lower beds, deposited farther out in the basin, are missing at San Pedro. However, since a faunal correlation was not important for the determination of ground water conditions, this phase was not studied in detail.

From the standpoint of ground water, the change in sedimentation brought about by the mid-Pleistocene revolution is most important, for

[4] Noble, L. F., *op. cit.*, page 12.

[5] Vaughan, F. E., Geology of the San Bernardino Mountains north of San Gorgonio Pass, Univ. Calif. Pub. Bull. Dept. Geol. Sci., Vol. 13, pp. 378–379, 1922.

* The term San Pedro formation, following the rather generally accepted manuscript usage by W. S. W. Kew (U. S. Geological Survey report) is restricted to the "lower San Pedro" of Arnold (Calif. Acad. Sci. Mem., Vol. 3, 1903), and the new name Palos Verdes formation, suggested by Kew is used in place of Arnold's term "upper San Pedro."

it marks the beginning of accumulation of the water-bearing alluvial gravel deposits in the three inland basins, and a change in the Coastal Plain basins from deposition of predominantly marine silts and clays to deposition of coarser material in which marine water-bearing sands and gravels formed a considerable part.

The base of these water-bearing deposits has in most areas been considered to be the bottom of the ground water basin. Blue-line contours on the geologic map, Plates A, B, and C, were drawn on the base of these deposits wherever there were sufficient well data.

Around the west and southwest side of the Puente Hills and southeasterly along the margin of the Coastal Plain toward Orange, the Upper Pleistocene is underlain by Lower Pleistocene conglomeratic beds that form a lower zone of water-bearing materials. Elsewhere locally, similar conditions exist.

Water well data were not complete enough in the deep central parts of the basins to permit extension of the contours into those regions, but scattered wells (shown on the map) indicate depths exceeding 1500 feet, and in some cases possibly 2000 feet.

Marine Upper Pleistocene.

The Upper Pleistocene marine sediments of the South Coastal Basin are confined definitely to the Coastal Plain area, and from the fact that throughout their vertical extent they grade laterally into continental deposits toward the north, east and south margins of the Coastal Plain, it is inferred that Upper Pleistocene seas never extended beyond the present margins of the Coastal Plain, and in most places did not reach the margins. Hence, Upper Pleistocene marine terraces were never cut into the inner hills around the Coastal Plain.

Several local erosional unconformities occur within the marine Upper Pleistocene, but these are probably confined to the marginal areas where they have been recognized, for the lithology and thickness of the deposits in the central Coastal Plain indicates continuous subsidence and deposition there.

The most prominent and widespread unconformity is that between the Palos Verdes sand and older beds. Dissected Palos Verdes sand occurs over a large part of the surface of the western Coastal Plain, and on most of the high areas along the Beverly-Newport uplift. It forms the lowest marine terrace deposit at San Pedro.

This unconformity can be recognized by angular discordance between the Palos Verdes sand and the beds beneath, at San Pedro and at several places along the Beverly-Newport uplift. It evidently occurs over a large part of the western Coastal Plain.

This combined Upper Pleistocene marine series is composed of bluish-gray sedimentary clays, gray micaceous and carbonaceous silts (sometimes peaty), gray poorly consolidated sands and loose gravels (see Plate VI, Fig. A). The section is thickest in the central part of the Coastal Plain, or along a line running southeasterly from the vicinity of Compton to Tustin. Although the maximum thickness of these unconsolidated deposits is not known exactly, wells penetrate loose gravels and sands to depths of 1500 feet or more before entering the silt series. It may be that the maximum thickness, determined on this basis of lithology, reaches 2000 feet. Occasional gravels and sands are

PLATE VI

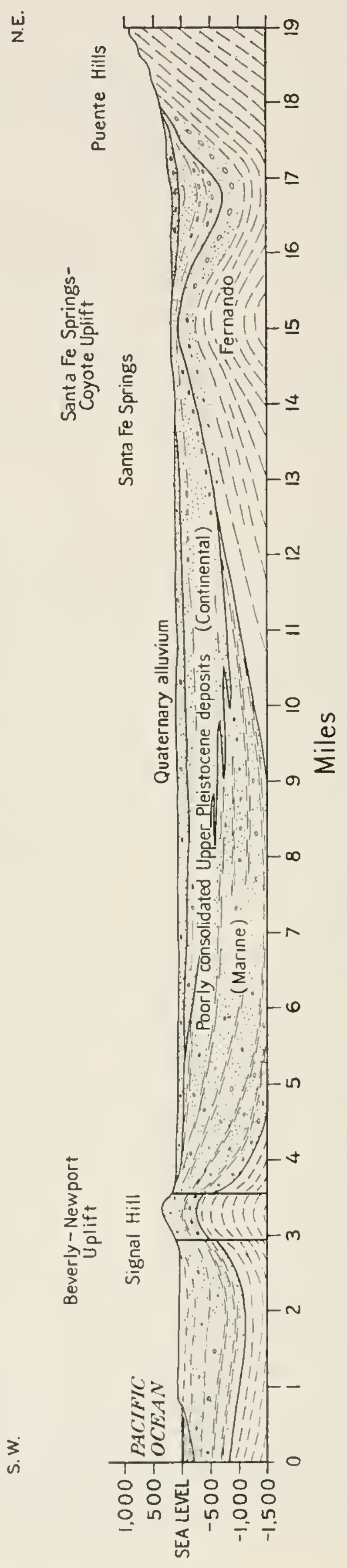


FIG. A DIAGRAMMATIC SECTION ACROSS SANTA FE SPRINGS-COYOTE, AND BEVERLY-NEWPORT UPLIFTS

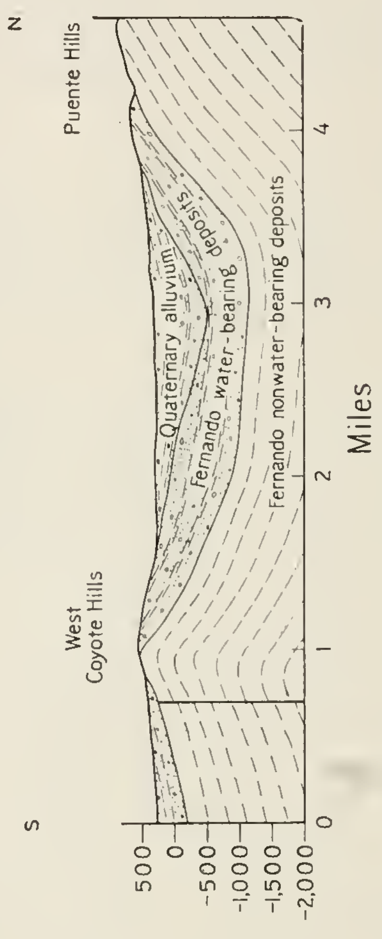


FIG. B DIAGRAMMATIC SECTION ACROSS LA HABRA SYNCLINE encountered in the Lower Pleistocene, even in the southwestern and western parts of the Coastal Plain area, and therefore, determination of the base of the Upper Pleistocene on the basis of lithology is not altogether simple.

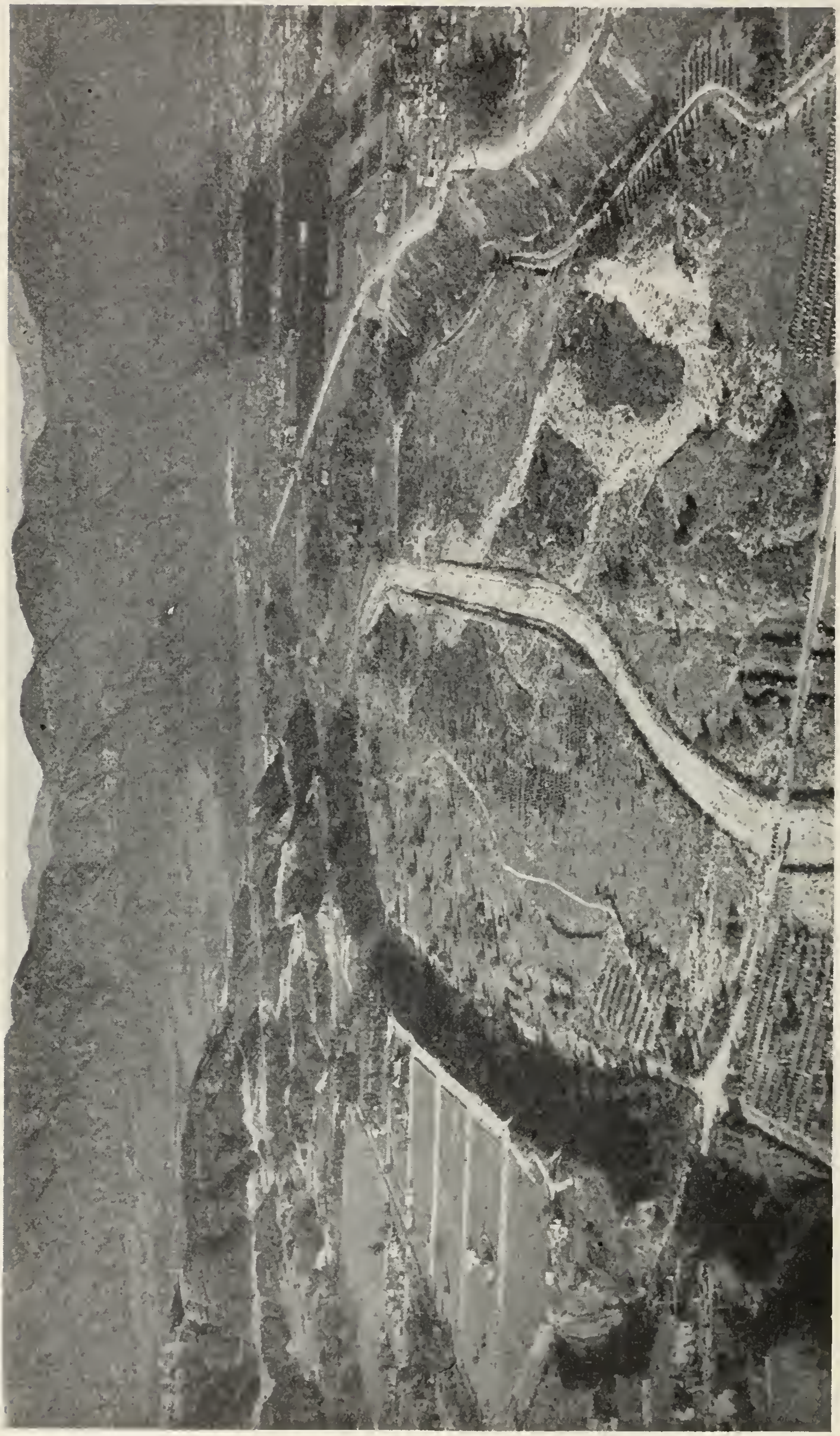
The Upper Pleistocene deposits thin rapidly toward the Beverly-Newport uplift, and toward the Santa Fe Springs-Coyote uplift, and are nowhere more than a few hundred feet thick along the axes of these structures. Evidently these structures were forming during Upper Pleistocene time. These relationships are indicated in Plate VI, Fig. A.

These Upper Pleistocene deposits are coarser toward the northeast side of the basin and finer toward the west and southwest. Silts and clays predominate over gravels and sands and the gravels are small along the western and southern parts of the basin. Pebbles more than two inches in diameter are uncommonly encountered in the gravels of this area. Toward the narrows of the Los Angeles, San Gabriel and Santa Ana rivers, the sediments become coarser, the coarsest cobbles commonly reaching four to five inches in diameter. The thick clay strata which form impervious caps over the sands and gravels in the southwestern part of the basin come to an end near the margin of the marine beds. These beds are poorly consolidated throughout, but contain some lime cement. Occasionally, sand or gravel beds are firmly cemented.

Gravel samples from water wells in the Upper Pleistocene deposits on the Coastal Plain are petrologically similar throughout the vertical range that they represent. The pebbles have been derived almost exclusively from the crystalline Basement Complex. Over the central Coastal Plain a typical assemblage includes a large proportion of gneissic materials; quartz-feldspar and biotite or hornblende banded gneisses, coarse-grained basic or acidic rather massive gneisses, and gneissic porphyries predominate. Granitic materials, aplite and pegmatite pebbles are present but less abundant. These are the rock types found in the San Gabriel River headwater drainage area. Toward the western Coastal Plain granitic and dioritic materials become more abundant and the gneisses become subordinate but common. Apparently the greater abundance of granitic and dioritic materials in this region is due to the influence of the Los Angeles River which drains more granitic areas in the western San Gabriels. In the north part of the western Coastal Plain the marine gravels contain an abundance of black slate, evidently derived from the Santa Monica Mountains. In the eastern Coastal Plain region granitic materials become abundant again, a pink feldspar variety being especially common. The change to granitic materials in this direction is due to the influence of the Santa Ana River, whose headwaters are in principally granitic types of rocks. Toward the southern part of the eastern Coastal Plain, black slates and dark colored volcanic or dike rocks appear, with occasional hard sandstone pebbles or cobbles, thus showing the influence of Santiago Creek which drains the western slopes of the Santa Ana Mountains. The sands are everywhere arkosic.

In short, the petrology of these Upper Pleistocene Marine deposits is, in general, similar to that of the overlying Recent deposits of the present streams, and consequently it follows that the principal streams which deposit sediments upon the Coastal Plain today have been in

PLATE VII



Arroyo Seco Wash, showing Recent alluvial surface (center) and Older alluvial benches (right and left). San Gabriel Mountains in background.

Spence Airplane Photo

existence throughout the accumulation of Upper Pleistocene deposits and were the chief contributors to the marine deposits. The scarcity of Tertiary volcanic materials and the general absence of concentrations of resistant materials such as pegmatites, quartzites, etc., so common in the Lower Pleistocene around the northeastern part of the plain, seems to show that the Tertiary sedimentary rocks of the intermediate belt of hills have contributed comparatively little to the marine Upper Pleistocene, and that the more distant high mountains have supplied most of the debris.

Continental Deposits.

The Continental Upper Pleistocene deposits of the South Coastal Basin occupy the three inland groundwater basins and occur around the inner portion of the Coastal Plain interfingered with the marine beds. They are commonly referred to as "Older alluvium."

The Kaegel and Lopez[1] fanglomerates are terrace deposits of Older alluvium that occur as high remnants on the mountain slopes north of San Fernando Valley. These remnants are not extensive.

The San Dimas[2] formation, which is exposed over a considerable area in the vicinity of San Dimas, between San Gabriel Valley and Upper Santa Ana Valley is there typical of the coarser facies of the Older alluvium. Vertebrate fossil material taken from a stream terrace 60 feet below the top of the formation and consisting of Elephas imperator (?) remains point rather definitely to Pleistocene age for the upper part of this formation. On the basis of fossil, physiographic and stratigraphic evidence, the Older alluvium of other parts of the South Coastal Basin can be correlated with the San Dimas formation. However, in spite of the fact that "Older alluvium" is a rather loose term, and in some cases confusing, it is used in preference to the term "San Dimas formation" in this report to designate the Upper Pleistocene continental deposits, because the term older, or earlier alluvium, has become so well established by general usage in groundwater reports, that the use of a formation name would obscure rather than clarify the discussion.

The Older alluvium outcrops at the surface as dissected alluvial cones, and locally as isolated low hills or mesas that stand above the general level of the Recent deposits around them. Plate VII shows the relation of Recent alluvium to Older alluvium on Arroyo Seco Cone. Older alluvium is generally distinguished from Recent alluvium on the basis of its topographic position and its characteristic deeply weathered reddish-brown clayey soil surface, grading downward into decomposed gravels. The distinction is difficult sometimes, however, where recently dissected alluvium is only slightly decomposed. These intermediate stages form a small part of the total, however. Where the Older alluvium does not outcrop at the surface it generally underlies the Recent alluvium at comparatively slight depths. Beneath that part of the Coastal Plain immediately east of the Beverly-Newport uplift, however, it is probably very thin or entirely absent, the Recent

[1] Hill, Mason L., Structure of the San Gabriel Mountains North of Los Angeles, California. Univ. Calif. Pub. Bull. Dept. Geol. Sci., Vol. 19. p. 144, 1930.

[2] Eckis, R., Alluvial Fans of the Cucamonga District, Southern California, Jour. Geol., Vol. 36, pp. 228, 235–236, 1928.

alluvium there lying directly upon the marine equivalents of the Older alluvium. These relationships are shown on Plate VI, Fig. A.

The Older alluvium of the South Coastal Basin has a thickness comparable to that of the Upper Pleistocene marine beds beneath the Coastal Plain. In San Fernando Valley it does not appear to have as great a thickness as elsewhere However, in the eastern part of the valley the total thickness of alluvium may reach 1000 feet (see Plate A) or more, all but a surface veneer being Older alluvium.

In San Gabriel Valley several wells have penetrated alluvial conglomeratic materials to depths of between 1200 and 1500 feet. The deepest of these are shown on the geologic map, Plate A. One well (Rancho Oil Well) southwest of El Monte penetrated continental beds to the depth of a little more than 2100 feet, entering upper Pico at that depth.[1]

Approximately the upper 1500 feet of the section were typical alluvial gravels, sands and clays. These probably represent the Upper Pleistocene and Recent debris from the San Gabriel Mountains.

The maximum known thickness of Older alluvium in upper Santa Ana Valley is a little more than 1400 feet. A well near Alta Loma, begun in Older alluvium, was bored to the depth of 1410 feet but failed to reach the base of the Older alluvium. In the vicinity of San Bernardino several wells more than 1000 feet deep end in alluvium. Two miles southeast of Claremont a well was bored to the depth of 1200 feet without reaching bedrock. The thickness of Recent alluvium is probably negligible in this well.

Beneath the Coastal Plain the maximum known thickness of alluvium is almost as great as it is in the inland basins. It can be seen from the geologic map, Plate B, that a short distance northwest of Brea, in the La Habra Basin, the Older alluvium has a maximum depth of about 1350 feet (Well No. C969g, Plate VIII). A well in this area penetrated 1355 feet of Older alluvium before reaching the La Habra conglomerate, its base being more than 900 feet below sea level. In this area the Older alluvium overlies the Lower Pleistocene conglomerate series that outcrops along the edge of the Puente Hills to the north and on West Coyote Hills to the south. It is thus dated as younger than the Lower Pleistocene beds. There is also a considerable thickness of alluvium in the arm of the Coastal Plain that extends southeasterly toward El Toro.

The bedrock floors of the inland basins are irregular and consequently the alluvial fill has a variable thickness, much of it being comparatively shallow. The contours at the base of the alluvium on the geologic maps give some idea of the relative thicknesses.

The Older alluvium, like the Recent alluvium, is made up of the debris that has washed down into the basins from the adjacent hills and mountains, and therefore contains the same assemblage of rock types that outcrop in the drainage areas. Crystalline rock types predominate except locally, as in the case of the La Habra Basin, where the alluvium is derived exclusively from the nearby hills of Tertiary sediments.

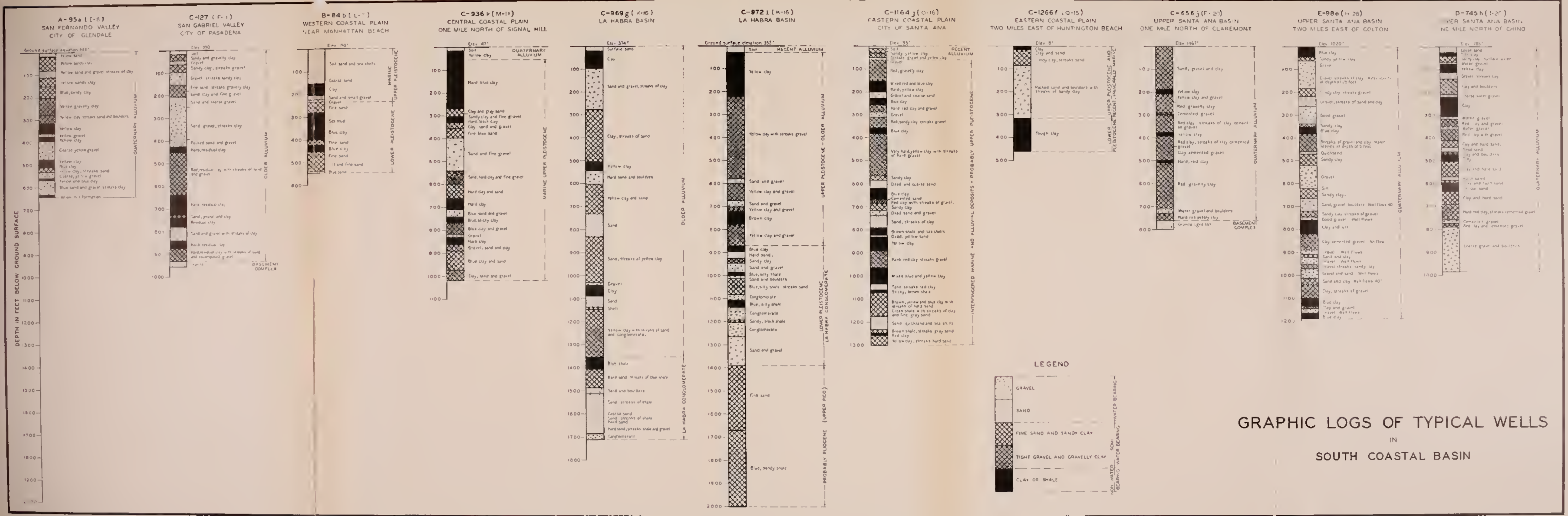
The coarse detritus is principally granitic and gneissic. Limestone, schist, quartzite, igneous dike rocks of many kinds, and volcanic mate-

[1] Correlation by Stanley Wissler, Union Oil Co.

PHIC LOGS OF TYPICAL WELLS

IN

SOUTH COASTAL BASIN



GRAPHIC LOGS OF TYPICAL WELLS
IN
SOUTH COASTAL BASIN

rials are less abundant, and locally black slate is present. The sands are arkosic and the silts usually micaceous. Throughout all the deposits derived from the Basement Complex there is an absence of apparent concentration of the hard quartzose types. There are probably two reasons for this. In the first place the Basement Complex types are all somewhat resistant to disintegration, and furthermore, alluvial debris which has merely traveled down a cone surface has not been sufficiently reworked to break down the less resistant types of material. Where the alluvium is derived from the Tertiary sediments, however, concentration of the hard materials is more evident. The granitic and especially pegmatitic materials make up the larger part of the pebbles and cobbles, with smaller amounts of sandstone and shale materials. The softer materials break down into sands, silts and clays.

The size distribution, based on the coarsest materials encountered in wells, is consistent with the present drainage lines, although the actual sizes may be considerably different from those in the surface channels above.

In the Coastal Plain area, the coarsest alluvial materials reported average about four to six inches in diameter. These are from wells near the heads of the cones of the larger streams on the Coastal Plain. Wells penetrating the alluvium between the larger cones around the inner margin of the plain show gravels with maximum sized cobbles usually about three to four inches in diameter.

In the inland basins the maximum sizes increase more rapidly toward the mountains. They run from about three to six inches at the lower edges of the basins up to boulders several feet in diameter in wells near the mountains. Outcrops of Older alluvium near the mountains show poorly sorted, sub-angular to moderately well rounded cobbles and boulders in massive deposits with very poorly defined bedding. The largest boulders sometimes are three feet or more in diameter. The coarsest materials occur beneath the steep slopes at the apices of the comparatively small cones, rather than beneath the less steep slopes at the cone apices of the large streams.

In studying these poorly consolidated alluvial deposits it has been found most convenient to group the materials into three lithologic units; namely, gravel, sand and clay; with subdivisions under each. The relationship of these groups to each other, together with their mode of origin is discussed rather fully in Chapter III, and the proportion in which they occur in different basins is discussed under the detailed descriptions of the basins, Chapters IV–VII. However, the characteristic features of the deposits as a whole are discussed briefly here.

The deposits of gravel, sand and clay contain fragments of all sizes. These fragments make up a continuous size series, beginning with the coarsest boulders at one end, and passing down through the sand grains to the finest of clay particles at the other end. The mechanical process of sorting separated the various sizes of materials so that they were laid down in beds of alternating coarser and finer materials, each bed containing a concentration of certain sizes, which identified it is a gravelly, sandy or clayey bed. No clay and practically no sand was deposited near the mountains, but on the lower parts of

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The deposits of Older alluvium as they occur today are not the comparatively simple series of beds that was deposited originally, for they contain clayey materials of two distinctly different types. The one, formed by actual deposition of fine particles in beds, has already been mentioned. It occurs beneath the lower flat parts of the valley floors. The other, formed by weathering above the water table of the deposits in place has in large part broken down the original gravels into tight gravels and clayey aggregates containing resistant pieces embedded in a clayey matrix. This second type of clay has been formed since the gravel deposits were laid down and is therefore a residual clay. It is characterized by reddish-brown color produced by oxidation of the iron-bearing minerals.

Observation of the materials from wells drilled on the upper slopes of the cones in the various basins has shown that in many areas, especially in those near the mountains and between the larger canyon mouths, the alluvium is a series of red beds made up of fossil residual soils, one above the other from bedrock to the surface, the uppermost soil of this type forming the characteristic reddish surface of the Older alluvium. Between the fossil soils, clayey yellow or red gravels, slightly decomposed gravels, and some rather fresh gravels occur. Toward the central and lower parts of the basins the red beds become more yellowish and less common. They are usually absent from the central flat parts of the basin. These relationships are shown in the graphic logs (Plate VIII).

The importance of these red beds can hardly be over-emphasized, for they are the characteristic deposits of the marginal regions of the alluvial basins and their influence is noticeable over a large part of all the alluvial deposits of the South Coastal Basin. The repeated formation of these soil beds during accumulation of the alluvium has so completely altered the original deposits in some areas near the mountains, that well logs show an average of more than 50 per cent of the materials to be clayey where no clay was deposited originally. Occasionally wells have penetrated nothing but these red clayey materials continuously for several hundred feet.

The character, origin and effect on the water-yielding capacity of the alluvium is discussed in Chapter III, under the heading of Weathering, pages 97–104.

Briefly, the formation of these red beds is the result of alternating dissection of, and deposition upon the upper slopes of the alluvial cones, and is the result in large part of the differential movements around the basin margins that have caused the basins to subside and the adjacent areas to rise.

Relation of the Upper Pleistocene Basins to the Adjacent Hills and Mountains.

The basins in which the Upper Pleistocene and Recent sediments have been deposited have subsided during accumulation of these deposits. This is evident from the fact that in all the inland basins and around the inner margin of the Coastal Plain continental (alluvial) sediments occur continuously from the surface down to depths several hundred to 1000 or more feet below sea level, and furthermore the equivalent marine beds on the Coastal Plain contain gravel and coarse sand beds throughout, thus showing that their thickness of some 1500 feet accumulated in shallow water.

On the other hand, marine terraces on San Pedro Hill, around the north and west sides of the San Joaquin Hills, and along the south front of the western Santa Monica Mountains, together with recent fault scarps, folds and other evidences of uplift elsewhere around basin margins give evidence that areas adjacent to the basins, now undergoing erosion, have been rising while the basins have subsided. Thus it seems probable that the positive (rising) areas have been undergoing continuous erosion throughout Upper Pleistocene and Recent time, and the negative (subsiding) areas have been continuously accumulating sediments during the same period. This period, therefore, can not be truly considered one of general uplift nor of general subsidence. Furthermore, it has not been a period in which general changes of sea level have shaped the sedimentary record. Although there have been minor oscillations of sea level throughout later Quaternary time these oscillations have been confined to a relatively small vertical range, probably a few hundred feet, and are not comparable to the vertical range of more than 2500 feet in Upper Pleistocene sediments represented by the difference in level between the lowermost beds in the basins and the upper marine terraces on San Pedro and other coastal hills.

Although erosion has been continuous in certain rising areas, and deposition continuous in certain subsiding areas, the marginal areas along the bases of the hills have had a complex history of alternating deposition and erosion. A study of conditions in these regions gives a picture of what has happened only in the immediate vicinity, and tells very little about the history of deposition out in the central parts of the basins. Thus at the east base of San Pedro Hills a few hundred feet of inclined San Pedro beds are overlain by horizontal Palos Verdes marine terrace deposits 50 feet or less thick. In the central part of the basin practically undeformed beds occur from the surface to depths of 1500 feet or more. At least the greater part of these beds are stratigraphically above the San Pedro series and give no evidence of erosional unconformity. The higher terraces on San Pedro Hill represent the stages of rest in the uplift of the hills during the interval between the time that the San Pedro beds were deposited and the Palos Verdes beds of the lowest terrace truncated them. It was during this erosion interval at San Pedro that the greater part of the 1500 or more feet of sediments above the San Pedro beds in the central part of the basin was deposited.

A similar situation of intermittent deposition exists at the north end of the San Joaquin Hills, where a cap 50 feet or so thick of horizontal Palos Verdes beds (at Costa Mesa) unconformably overlies inclined Lower Pleistocene and Pliocene strata and laps over into the Miocene. The higher terraces on the hills were cut during the interval between deposition of the inclined strata and the overlying horizontal terrace beds. Like conditions are indicated along the Beverly-Newport and Santa Fe Springs-Coyote uplifts by the comparatively thin section of Upper Pleistocene beds on these uplifts.

The alluvial sediments around the inner margin of the Coastal Plain and those around the margins of the inland plains show even more clearly the effects of differential uplift at the basin margins. As mentioned earlier, the alluvium near the hills and mountains is composed of a series of reddish-brown residual clays (fossil soils) interbedded with less weathered gravels. Each of these fossil soils developed at the surface during a period when the cone was undergoing erosion, just as today the dissected cone surfaces are covered by similar soils. Thus the repetition downward of clayey fossil soils between less weathered gravels represents a series of slight local unconformities from the surface to bedrock. These buried red clays, abundant at the edges of the basins, become fewer and farther between toward the center and finally disappear entirely. Thus they mark the transitional zone between continuous erosion in the hills and continuous deposition in the central parts of the basins.

Stratigraphic Evidence Concerning the Period of Deformation.

Throughout the Coastal Plain Basin the gravels do not appear uniformly at the same stratigraphic horizon in different areas. For example, Pliocene and Lower Pleistocene conglomerates in the vicinity of the Puente Hills correspond to silts and sands over most of the central and western part of the Coastal Plain region.

At the Baldwin Hills, the shale and sand section extends to the top of Timms Point zone (Lower Pleistocene). At San Pedro, the San Pedro series is principally sand. At Seal Beach, occasional gravels occur in the Timms Point and upper Pico. Similar conditions exist at Huntington Beach. In the Upper Pleistocene, however, gravels are abundant and widespread even in the western Coastal Plain Basin, and although coarse water-bearing materials occur within and below the San Pedro series they are local and comparatively rare. Evidently there was deformation in parts of the basin long before the intense mid-Pleistocene revolution began, but at that time deposition of coarse materials became general.

STRUCTURE

The South Coastal Basin for the most part lies between two areas that are markedly different in structure. Along the north side lie the east-west ranges that cross southern California transverse to the predominant northwest-southeast structures of the Coast ranges, and to the south lies the northern margin of the Peninsular ranges, through which northwest-southeast structures run. There is a sharp transition within the South Coastal Basin from the thick plastic series of sediments near the coast to the rigid crystalline (Basement Complex) rocks in the interior. Because of this unusual physical set-up, the complex structural pattern of the South Coastal Basin is unlike that to the north or south.

Two major structural trends are prominent in the area, however. One is a series of compression folds and faults trending nearly east-west. The other is a series of northwest-southeasterly striking shear faults, along which the southwest blocks, in some instances, at least, have moved progressively northwest with respect to the adjacent northeast blocks. Locally the E.-W. structures are rotated toward alignment with the NW.-SE. shear planes. The map, Plates A, B, and C, shows the major structural features of the region.

In areas where the Tertiary sediments are thick, the principal relief to compressive stresses has been by folding, and where the sediments are thin or entirely absent, these stresses have in the main been relieved by faulting.

MAJOR FAULT ZONES

NW.-SE. System.

There are five principal fault zones of the NW.-SE. system within the South Coastal Basin, and several others less prominent.

The San Andreas fault is the master fault of the NW.-SE. system. It runs southeasterly through the northeast corner of the South Coastal Basin, entering it at the head of Lone Pine Canyon. It runs down the canyon, crosses Cajon Pass, runs along the southwest base of the San Bernardino Mountains, then swings more easterly, running through the hills north of San Gorgonio Pass into Salton Basin. It is the largest and best known fault in California and its surface trace marks a continuous line of fracture for nearly 600 miles, from the vicinity of Point Reyes north of San Francisco southeasterly to the Salton Basin. This fault separates the crystalline rocks of the San Bernardino Mountains from the alluvial basin.

Recent topographic displacements along this fault show the latest movements to have been principally horizontal, the northeast side having moved southeast with respect to the southwest side. There is a suggestion in the rock types along the fault that this movement has been progressive, the accumulated total being measurable in miles. Noble[1] has pointed out that the Pelona schist outcrops continuously on the southeast side of the fault for 50 miles while many different kinds of crystalline rocks outcrop on the northeast side opposite the schist. Furthermore, he has mapped two separate Tertiary sandstone areas alike in lithology, on opposite sides of the fault. That on the northeast side is shown on the map in Cajon Pass. The other lies 24 miles northwest and outside the basin. Should it be true that these apparent horizontal displacements are real, then it seems reasonable to suppose that the San Bernardino Mountains and the San Gabriel Mountains were once one, and have been separated by movement on this fault.

Another series of faults enters the South Coastal Basin in the vicinity of Lytle Creek and parallels its course to the Upper Santa Ana Valley. Two or more faults are recognizable throughout most of the length of Lytle Creek, the more southwesterly being known as the San Jacinto fault. The other zone is about one mile northeast of the San Jacinto fault where it enters the alluvial basin from the northwest. These two nearly parallel fault zones cross the Upper Santa Ana Valley. The northeast zone passes along the northeast edge of Loma Linda, and for convenience the name Loma Linda fault is here applied to it. The two zones converge toward the southeast and are less than one-fourth mile apart where they leave the South Coastal

[1] Noble, L. F., The San Andreas Rift and Some Other Active Faults in the Desert Region of Southeastern California, Bull. Seis. Soc. Am., Vol. 17, pp. 30–31, 1927.

Basin. The San Jacinto fault is the more prominent of the two and shows more evidence of recent movement.

About 20 miles southwest of the San Jacinto fault, the Elsinore fault zone forms a graben two to three miles wide between the Perris block and the Santa Ana Mountains. Lake Elsinore and Temescal Wash lie within this complexly faulted area. A short distance south of Corona the principal fault of the zone splits. One branch, the Chino fault, swings northerly along the northeast edge of the Puente Hills, and apparently dies out before reaching the San Gabriels. The other, the Whittier fault, swings more westerly, running through the southwest part of the Puente Hills, and finally becomes lost under the alluvium at Whittier Narrows.

A fourth fault zone of the NW.-SE. system cuts through the Coastal Plain and coincides with the Beverly-Newport uplift. It is known as the Inglewood fault zone. From the map, Plate B, it can be seen that the surface expression of this zone is a series of short disconnected faults with a roughly en echelon arrangement, associated with a series of en echelon folds. There has been considerable Recent activity along this line, as indicated by the surface expression in the Quaternary sediments. However, the main continuous fracture, if there is one, is deeply buried and movement along it has been imperfectly transmitted upward through the thick mantle of sediments.

The most westerly zone of the NW.-SE. system runs along the northeast base of the San Pedro Hills. Here again there is no continuous fault at the surface. It is a localized zone of intense deformation in which Recent faulting has played a minor part.

E.-W. System.

Faults of the E.-W. system are in most instances short and highly variable in strike. They are generally convex toward the south and irregular in trace. There is an absence of evidence of horizontal movement, so characteristic of the NW.-SE. faults.

Faults of this system run along and near the south base of the San Gabriel Mountains throughout their entire length. West of Santa Anita, these mountain front faults swing northwesterly to the vicinity of Big Tujunga River, beyond which they again run westerly. North of the mountain-front faults, the range is cut through the middle by the east-west San Gabriel fault zone. The south fault of this zone roughly parallels the east and west forks of the San Gabriel River and lies one-half to one mile north of them. It is a steep reverse fault and comparatively straight, in this respect being different than most E.-W. faults.

A zone of faulting, not everywhere evident, runs along the south front of the Santa Monica Mountains. A continuation of this line runs easterly cutting the alluvium south of Pasadena and joins the San Gabriel mountain-front faults at Monrovia Canyon. In this area the fault is known as the Raymond fault.

In the San Bernardino Mountains, east of the San Andreas fault, several large reverse faults trending southeasterly near the San Andreas fault swing easterly into the mountains. Upthrow is on the northeast or north side of these faults.

There are many comparatively small, short faults, some cutting alluvium, others in the Tertiary sediments south of the Santa Monica and San Gabriel Mountains that belong to the E.-W. system. Some of these faults are so variable in strike that they could not be considered a part of the E.-W. system if it were not for their apparent relationship to other faults of the system.

CHARACTER OF THE DEFORMATION

The NW.-SE. faults are characteristically long, comparatively straight or gently curved steep to vertical faults, along many of which the movement has been principally horizontal. Faults of the E.-W. system are strikingly different from those of the NW.-SE. system. Where these faults have been studied in detail they have generally been found to be moderate to steeply dipping thrust faults, the mountain blocks being thrust southerly up over the valley blocks. In the Tertiary sediments many east-west trending folds reflect the same stresses that have produced the thrust faults.

In a general way the old crystalline structures in the Basement Complex show the same trends that the later structures have developed. Throughout the San Gabriel and San Bernardino mountains, the schistosity and gneissic banding in the crystalline rocks has a regional strike that is generally a little south of east over broad areas. In certain zones, like that in the vicinity of Lytle Creek, the crystalline structures more nearly parallel the NW.-SE. system. Attitudes of the schistosity are locally variable, and any attitude may occur.

South of Riverside (on the Perris block) the gneissic banding is prominent for many miles to the southeast, its regional strike being N. 30 to 40 degrees W., a little more northerly than the later structures. Elsewhere in the older rocks these structures are evident.

The presence of these two trends, in the old crystalline structure and in the later deformation alike, indicates one of two things. Either the same or similar forces that acted to produce the old crystalline structures, produced the Pleistocene deformation, or, the Pleistocene deformation resulted from different stresses, but was shaped by the old basement structures which offered the lines of least resistance to deformation.

Faults of the two systems are not everywhere readily distinguishable and several faults are clearly a composite of the two systems. Other faults do not appear to be related directly to either system. Near the western end of the San Gabriel Mountains, the San Gabriel fault zone changes from a NW.-SE. zone to an E.-W. zone. Farther south the Whittier fault swings around to nearly an east-west strike along the south side of the Puente Hills. There are several other similar examples of this change of trend. In fact there are only two NW.-SE. zones of faulting, the San Jacinto and the San Andreas, that cut through the transverse ranges. The others either die out or pass into faults of the E.-W. system.

Apparently there is a close relationship between the two systems, and from the character of this relationship it seems probable that the tendency of northwest-southeast shearing to change to north-south shortening by folding and thrust faulting is the result of some difference in the character of the earth's crust which permits relief of the stresses more easily along east-west lines than northwest-southeast lines within the transverse zone. Possibly this tendency is due to the influence of the old crystalline structures of the Basement Complex, mentioned above.

The general structural pattern, with east-west trending compression faults and folds, and horizontal shear planes developed diagonal to the axes of compression, may be due to rotational compression stresses with the chief components in a north-south direction.

Age of the Deformation.

The structure of the old Basement Complex rocks, together with numerous unconformities throughout the Tertiary and Quaternary sediments shows that there have been a number of periods of deformation in this region. However, the intense deformation that has produced the structures so important to the storage and movement of ground water in the South Coastal Basin, has occurred at a very late date geologically. Deformation of the Lower Pleistocene deposits is nearly as great as that of the older sediments, thus dating the period of intense deformation as post-Lower Pleistocene. As indicated on the geological maps, most of the faults in or along the edges of the groundwater basins displace Older alluvium or its marine equivalent. Many low scarps and other evidences of Recent movements mark the surface traces of the principal faults where they cross older alluvial surfaces. These features show displacements of the surfaces, ranging from a few feet to more than 200 feet. Along the same fault, displacements are progressively greater with earlier surfaces.

In a few cases Recent alluvial surfaces are displaced, but in no cases are the surfaces of alluvial washes of the present streams cut. Along the most active faults, surfaces so recent that they are practically unweathered have been displaced.

The most recent activity appears, from the freshness of surface features, to have been along three fault zones of the NW.-SE. system, the San Andreas, the San Jacinto and the Inglewood. Although movements of comparable recency have occurred along all three of these lines, and apparently at a few places along the Elsinore zone, the greatest activity has occurred along the San Andreas fault.

Faults of the E.-W. system have not displaced undissected Recent surfaces, but have in a few places cut across surfaces so recently dissected that they are only slightly weathered. It may be that the more recent appearance of fault features along certain of the NW.-SE. zones, is due to more frequent activity, and does not mean that activity has ceased on faults of the E.-W. system.

Evidently the intense deformation that upheaved the early Pleistocene and older deposits alike, has continued into Recent time, and is, in fact, still in progress.

THE COASTAL PLAIN

The Coastal Plain is divided structurally into three parts by the Beverly-Newport and Santa Fe Springs-Coyote uplifts. The Beverly-Newport uplift, or Inglewood fault zone, is a localized zone of deformation about one-half to one mile wide that runs through the Coastal

Plain from the base of the Santa Monica Mountains southeasterly, probably passing into the ocean in the vicinity of Newport. This structure is anticlinal; the beds dip away from it on either side. A number of en echelon folds with axes trending nearly east-west have developed along the structure and have permitted the accumulation of oil in the anticlinal folds. The Inglewood, Rosecrans, Dominguez, Signal Hill, Seal Beach, Huntington Beach, and possibly Costa Mesa oil fields occur on these structures.

There is no continuous fault at the surface that runs the length of the structure. From Signal Hill north there is a series of short, nearly north-south faults that cut the trend of the structure at a sharp angle (see Plate B). These faults show displacements of only a few feet at the surface. In the Inglewood field, however, the fault that cuts through the field has a throw of about 350 to 400 feet, the east side having been elevated.

Southeast from Seal Beach there is apparently one fault that is continuous to Huntington Beach and probably beyond. The surface trace of this fault is about a half mile from the ocean. Another fault branches off north of Huntington Beach and trends more easterly across Huntington Beach Mesa. Oil well data indicate that the subsurface throw of the eastern fault is 1200 to 1300 feet, and that of the western fault about 150 to 200 feet. In both cases the northeast sides have been uplifted. The surface traces of these faults can be seen where they cross the old marine surface, but they do not cut the Recent surfaces in the gaps between the mesas.

The Beverly-Newport structure forms an effective barrier to the movement of ground water, both by sealing of the pervious strata through faulting, and by bringing the impervious silts to, or near to the surface along the uplift. Low places occur along the structure and those in which the upper strata are not faulted permit the escape of ground water near the surface. The Dominguez gap is the principal one through which ground water escapes.

West of the Beverly-Newport uplift, the only structures that form ground water barriers are the zone of deformation along the northeast base of the San Pedro Hills, the Playa del Rey anticline at Venice, and one or two east-west structures a short distance south of the Santa Monica Mountains. The Torrance anticline does not act as a barrier to ground water movement,* although the deeper water-bearing beds are probably slightly deformed by it. The Playa del Rey anticline acts as a partial barrier, probably by bringing silts up near the surface.

Northeast of the Beverly-Newport uplift the central and eastern Coastal Plain areas overlie a great synclinal trough 50 miles long the axis of which runs northwest and southeast. In this area there are no structures in the water-yielding strata that interfere with the natural

* A dome-like, high water table is shown on Mendenhall's map (U. S. Geol. Survey W.S.P. 139, Pl. V, 1905) east of Redondo, that coincides roughly with the Torrance anticline. This water table dome disappears when the water level elevations are corrected to conform to the revised surface topography shown on the United States Geological Survey Torrance Quadrangle, published in 1924. The topography used by Mendenhall was taken from the Redondo Quadrangle surveyed in 1894. The maximum topographic discrepancies between the two maps occur near the top of the apparent water table dome where the surface shown on the older map is about 25 feet higher than that shown by the later survey. Evidently the apparent high water table is due to plotting from incorrect topography.

movement of ground water and it is thought, therefore, that no faults or anticlines of importance occur in the upper strata of this region.

East of San Gabriel River the Santa Fe Springs-Coyote uplift, which is a series of east-west striking structural domes, separates the La Habra syncline to the north from the main Coastal Plain. Santa Fe Springs, west and east Coyote and Richfield oil fields are located on domes along this structure.

There appears to be a sub-surface fault that runs along the south margin of this structure from the mouth of Santa Ana Canyon westerly almost to Santa Fe Springs. The water table north of this line stands higher than that of the central Coastal Plain. It is possible, however, that sharply folded beds rather than faulting, are responsible for water table differences.

Except in the Coyote Hills, the silts do not come to the surface along this uplift, and consequently the ground water moves across the structure elsewhere. The La Habra syncline runs from the San Gabriel River near Whittier southeasterly toward the mouth of Santa Ana Canyon. It is asymmetric, its axis lying near the north side of the valley. Lower Pleistocene conglomerates are folded down beneath the alluvium in this basin and form a lower water-bearing zone. Plate VI, Fig. B, shows an N.-S. section across this syncline.

The Intermediate Belt of Hills.

The intermediate belt of hills and mountains are, in the main, a series of folded and faulted Tertiary sediments throughout which the predominant trend of the structures is east-west. North of Los Angeles and between Los Angeles and the San Gabriel Valley, some structures swing southeasterly, apparently reflecting the similar flexure in the east-west structures of the San Gabriel Mountains to the north. Near the eastern end of the hills, and especially in the northeastern San Jose Hills, the structures swing slightly northeasterly.

The Santa Monica Mountains, which form the western part of these hills, are a large complexly faulted anticlinal structure with a crystalline core. This structure strikes E.-W. and ends at the Los Angeles River. The mountains are faulted up on their south side along a fault zone that is concealed beneath the alluvium to the south. The Raymond fault forms the continuation of this same line to the east, running easterly through the hills and across the San Gabriel Basin to Monrovia Canyon.

Northeast of the Santa Monica Mountains the Verdugo mountain-block is faulted up along its southwest side and tilted northeasterly.

In the hills east of Los Angeles, the structure is very complex. The sediments are closely folded and faulted. Several of these faults and folds are shown on the map, Plate A, but many other smaller structures are present also. The Montebello anticline forms the east nose of these hills at Whittier Narrows.

The Puente Hills form a triangle that lies south of San Jose Valley, and between the Whittier and Chino faults, which join near Corona. The structure in these hills is somewhat irregular and folds and faults do not in all cases conform to either the NW.-SE. system or the E.-W. system. The hills have been faulted up between the Chino and Whittier faults, and the straight traces of these faults suggest that there has been also some horizontal movement. Both of these faults are steep. One exposure of the Chino fault was seen, showing it to be a steep reverse fault. North of the Puente Hills a series of easterly to slightly northeasterly trending folds in the Tertiary sediments form the San Jose Hills. Locally they are faulted, the principal one being the San Jose fault (Plate A) that runs along the south side of the hills near their eastern end, and out into the alluvium to the northeast.

The Inland Basins.

The three inland basins are structurally low areas that comprise the depressed belt immediately south of the high San Gabriel and San Bernardino mountains. Although these basins are each distinct structural units, they are connected by narrow alluvium-filled structural depressions that lie at the base of the mountains.

Where these basins are underlain by considerable thicknesses of Tertiary sediments they have been depressed principally by folding, and where underlain by crystalline rocks they have been depressed in the main, by faulting.

In the San Fernando Basin, the series of east-west folds around the western margin plunges easterly into the basin, forming a synclinorium. The basin gradually deepens and broadens toward the east, where it is cut off abruptly by the up-faulted southwest front of the Verdugo Mountains. In the northeast corner of the valley, near San Fernando and eastward to the mouth of Tujunga Canyon, the floor of the basin is several hundred feet above that of the main basin. The eastern part of this area has been faulted up along the fault that uplifted the Verdugo Mountains, and the western part has been separated from the main basin by the anticline and faults running easterly from the vicinity of San Fernando dam (see Plate A). Within this area there are three small structural subbasins, each of which has a different water table, and all more than 300 feet above the main basin water table. A rather low angle thrust fault at the base of the San Gabriel Mountains forms the boundary of the most northerly of these subbasins.

The central part of the main San Fernando Basin is free from structures that interfere with the movement of ground water. It seems probable therefore that it is a rather simple synclinal region.

The San Gabriel Basin is faulted down along its entire north margin. The northwest part of this basin is separated from the main basin by the Raymond fault that forms an escarpment in the alluvium 50 to 150 feet high, running westerly from the mouth of Monrovia Canyon to the Arroyo Seco at the south end of the San Rafael Hills. Although the alluvial surface has been displaced vertically a maximum of only about 150 feet, water well logs near the western margin of the basin indicate that the bedrock north of the fault has been uplifted several hundred feet. At Raymond Hill near South Pasadena, the Topanga conglomerates immediately north of the fault have been overturned. This fact, together with evidence of reverse faulting east of Monrovia Canyon along the same line, suggests that the Raymond fault is a reverse fault. A short distance north of the Raymond fault the Eagle Rock fault enters the basin from the west. This fault is an old reverse fault, and does not affect the alluvium nor the movement of ground water.

The Pasadena area, which lies north of the Raymond fault, is separated from Monk Hill Basin near the mouth of Arroyo Seco Canyon by a bedrock ridge which extends southeasterly from the San Rafael Hills. Monk Hill, a part of this ridge, protrudes through the alluvium. There is no direct evidence that this ridge has been produced by faulting, but a continuation eastward of a fault in the hills (Plate A) nearby would pass along the south side of the Monk Hill "dike." The ridge may have been uplifted along this fault.

At several places along the base of the mountains, reentrants of the alluvial basin cross the mountain-front fault zone. In all these cases the faults cut the alluvium and act as barriers to the movement of ground water, thus forming small subbasins along the mountain front.

In the eastern part of the basin near San Dimas, several hills protrude through the alluvium, and these hills together with local bedrock irregularities divide the area into several subbasins. These bedrock features are probably due in part to east-west folds or faults, but are probably also, in part, irregularities in an old buried erosion surface.

The entire San Gabriel Basin south of the Raymond fault is underlain by Tertiary sediments, and the old erosion surface on the sediments has apparently been warped or folded down in the southeast, south and southwest portions of the basin. There is no evidence that faults cut the alluvium near these margins. There is a rather sharp break in the bedrock floor beneath the alluvium, however, near the west margin of the basin. On the map, Plate A, this break in the slope of the bedrock floor can be seen running in a nearly straight line southeasterly from the west base of Monk Hill to the point of the hills on the west side of Whittier Narrows. This line may have been determined by an old fault that does not cut the alluvial surface.

The Whittier Narrows, which affords the only important avenue of escape for the ground waters of San Gabriel Basin, is a structural feature. Although faulting may have played a part in the formation of this opening, there is no indication of it in the behavior of the ground water, and it therefore seems probable that the narrows is essentially a northeast-southwesterly trending syncline filled with alluvium. The east point of the Montebello anticline terminates rather abruptly at the narrows, and it may well be that it is cut off by a fault whose influence on the ground water has not been detected.

The structures in the San Gabriel Basin that have been described all occur at or near the margins of the basin. The Raymond fault, which cuts off the northwest corner of the basin, is the farthest from the margin. The central part of the basin is free from any structures that interfere with the movement of ground water.

The Upper Santa Ana Basin, over most of its area, is underlain by crystalline rocks which form a comparatively rigid floor. Consequently the basin has been depressed principally by faulting. Its west, north and east boundaries are formed by fault blocks.

The Cucamonga fault zone runs along the north margin of the basin and separates the thick alluvial deposits from the crystalline rocks of the San Gabriel Mountains. The San Andreas fault forms the straight northeast margin of the basin, separating it from the San Bernardino Mountains. The west and southwest margins of the basin have been determined by faulting. The Chino fault zone runs along or near this margin from the vicinity of Corona to a point near Pomona, where it is cut off by the San Jose fault. A fault runs also along the northeast margin of the San Jose Hills, where they meet the basin. There is no direct evidence of faulting along the southern edge of the basin west of Redlands, and it may be that this irregular margin is a northward sloping erosion surface that passes beneath the alluvium.

Several faults cut through the alluvium within the basin, and act as barriers to the movement of ground water. These faults form sub-basins in which the ground water generally stands at higher levels than in the central part of the basin. One of these, the San Jose fault, runs northeasterly from the east tip of the San Jose Hills through the alluvium, reaching the mountain-front a short distance east of the mouth of San Antonio Canyon. Although the surface trace of this fault has been eradicated by Recent alluvial deposits, the fault forms a well-defined ground water barrier, commonly referred to as "the Pomona dike." The Pomona Basin area lies northwest of this line. Another fault strikes east-west through the northern part of this area, passing along the south side of Indian Hill, which is an uplifted alluvial remnant.

Northeast of Upland, the Cucamonga Basin has been formed in a similar manner. Here, a fault, convex toward the south, forms a ground water dike beneath the southern margin of the Red Hills that holds back the waters percolating southward from Cucamonga Canyon.

The eastern part of Upper Santa Ana Basin is effectively cut off from the remainder of the basin by the San Jacinto fault which forms the well-known Bunker Hill ground water dike. This dike is a continuous fault plane barrier in the alluvium, that runs from the mouth of Lytle Canyon southeasterly in a practically straight line across the basin and into the hills a short distance west of San Timoteo Canyon. The Bunker Hill artesian basin (page 151) lies northeast of this dike. The San Jacinto fault is a line of recent movement and can be readily traced by a series of fault features on the surface. It is the best defined and most effective fault barrier to the movement of ground water in the South Coastal Basin.

About one mile northeast of San Jacinto fault, the parallel Loma Linda fault zone cuts through the basin. The Lytle Creek Basin lies between these two faults in the northwestern part of the area. Toward the central part of the basin, the effect of this second zone of faulting upon the ground water is masked by that of the Bunker Hill dike which has caused an artesian area that extends far beyond the Loma Linda fault zone.

Northeast of San Bernardino a group of hills protrudes through the alluvium, running southeasterly from the lower end of Cajon Canyon. The alluvium-filled trough between these hills and the San Andreas fault is called the Devil Canyon Basin. The comparatively straight northeast front of these hills suggests that they have been faulted up along that side.

The isolated low mountains and hills that protrude through the alluvium in the vicinity of Riverside are partly buried remnants of erosion, and not due to structural displacements.

Southeast of Redlands, in the Yucaipa-Beaumont region, there is a large ground water basin, isolated both structurally and physiographically from other parts of the Upper Santa Ana Basin. This basin is formed by a series of gravels, sands and clays (San Timoteo beds) folded into a broad syncline and overlain in this syncline by Quaternary alluvium. The axis of the syncline lies beneath the southwest part of the Yucaipa-Beaumont Plain. The southwest limb is exposed throughout its length of about 20 miles, along San Timoteo Canyon. The ground water moving southwesterly through the alluvium from the high mountains is brought to the surface where the folded beds emerge from beneath the southwest edge of the plain, and springs occur where the canyons cut previous folded beds.

The San Timoteo beds are cut off against the San Jacinto fault along most of their southwest margin, but the Loma Linda fault which cuts through these beds a short distance to the east is probably also an effective barrier to movement of the ground water.

North of Yucaipa the Crafton Hills have been faulted up on a series of faults along their south side. These hills form a bedrock dike between the Yucaipa Basin and Bunker Hill Basin.

The High Mountains.

The three mountain ranges, the San Gabriels, San Bernardinos and Santa Anas, that form the high mountains of the South Coastal Basin, are all fault blocks that have been uplifted in late Pleistocene and Recent time to their present height from regions of low or moderate relief.

San Gabriel Range. Within the South Coastal Basin there are two principal belts along which the San Gabriel Mountains have been uplifted. One is a belt along the front of the mountains marked by series of north-dipping thrust faults in cusp-like overlapping arrangement, with the ends of individual faults running back into the mountains and ending. The other belt runs through the interior of the range paralleling the east and west forks of San Gabriel River and lies one-half to one mile north of them. There may have been some uplift along the San Jacinto and adjacent fault zones of the NW.-SE. system that cut across the northeast side of the mountains. Faults of the southwestern San Gabriel Mountains have been described and mapped in a general way by Miller,[1] but later work has required some revision of these lines.

The zone of faulting along the mountain-front is, in the western part, called the Sierra Madre fault zone. This zone runs along the front of the mountains at and near their base, from the western end of the range east to the vicinity of San Antonio Canyon. Eastward from Dalton Canyon, however, the south fault of the range diverges widely from the main zone and runs along the base of a group of foothills south of the main mountain-front. This fault zone from Dalton Canyon eastward to Lytle Creek is called Cucamonga fault. East of Cucamonga Canyon it forms the mountain-front fault zone. The Sierra Madre zone passes back into the range near San Antonio Canyon

[1] Miller, W. J., Geomorphology of the Southwestern San Gabriel Mountains of California, Univ. Calif. Pub. Bull. Dept. Geol. Sci., Vol. 17, pp. 193–240, 1928.

and probably continues through the mountains, running down the south fork of Lytle Creek to the San Jacinto fault.

The western part of the Sierra Madre fault zone has been discussed by Hill,[2] who has pointed out and described two important thrust faults along the mountain front between Pacoima and Big Tujunga canyons. These arcuate faults, though quite irregular in strike, have a general northwest-southeast trend and dip under the range at angles varying from 15 to 70 degrees. Basement Complex has been faulted up over Saugus (Lower Pleistocene) beds. Southeasterly toward Arroyo Seco from Tujunga Canyon the details of the mountain-front fault zone have not been worked out. North of Altadena two well-defined thrust planes with thick gouge zones, and several other less distinct faults, are exposed in road cuts. These faults strike nearly E.-W. and dip northerly at angles of about 55 degrees.

The Cucamonga and Sierra Madre fault zones east of Monrovia Canyon have been studied in some detail.[3]

The Sierra Madre fault system between Monrovia Canyon and San Dimas Canyon includes a system of nearly parallel, moderate to steep north-dipping thrust planes that have produced a series of salients along the mountain-front.

One reverse fault runs southeasterly from the mouth of Monrovia Canyon toward San Gabriel Canyon, swinging around to an easterly or northeasterly strike as it approaches this canyon. The eastern part of this fault is concealed beneath alluvium, but water levels indicate that it lies close to the mountain-front and strikes toward the mouth of San Gabriel Canyon. This fault zone, at the mouth of Monrovia Canyon, has a crushed zone 30 feet wide in the Basement Complex. Its strike is about N. 75 degrees W., and its dip, 45 degrees N. Another exposure of this fault one mile east shows the attitude there to be N. 72 degrees W. and 42 degrees N. Another nearly parallel fault, a short distance south of the mountain-front, has uplifted Quaternary alluvium 150 feet or more, north of Duarte, and produced the old dissected benches along the mountain-front.

Two or more faults of the Sierra Madre zone appear from water level data to cross the alluvial reentrant at the mouth of San Gabriel Canyon or join other faults from the east.

Four major faults were traced from the mouth of San Gabriel Canyon almost to Dalton Canyon, where they are covered by a landslide. Where exposures were seen these faults were found to dip northerly from 40 to 60 degrees. The fault traces are slightly convex toward the valley. Three of these faults lie along the mountain-front and a fourth lies about one-half mile south of it. These faults are shown on the geologic section MN, Plate A. Attitudes in crushed zones indicate north dips of 40 degrees to 60 degrees. The fault traces are slightly convex toward the basin and spread from almost a common point at the mouth of San Gabriel Canyon to a distance apart of more than one-half mile near Dalton Canyon.

The most southerly of the three mountain-front faults follows closely the base of the mountains and brings Miocene andesitic or basaltic lavas

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[2] Hill, Mason L., Structure of the San Gabriel Mountains, north of Los Angeles, California, Univ. Calif. Pub. Bull. Geol. Sci. Vol. 19, pp. 137–170, 1930.

[3] This study includes a preliminary investigation by the author for the Metropolitan Water District of Southern California, in 1930, supplemented by the present investigation by the Division of Water Resources.

up over Quaternary alluvium. The fault contact seen about three-fourths of a mile east of San Gabriel Wash dips 60 degrees N. The middle fault thrusts massive Basement Complex up over the Miocene lavas. The northern fault thrusts the Basement Complex up over similar rocks and locally over patches of lava which lie on the Basement Complex below the fault.

The fault that lies south of the mountain-front brings Miocene sediments up against the alluvium of the valley, and produces a bench north of it similar to that north of Duarte.

The salient between Dalton and San Dimas canyons is covered by a large landslide of andesite and basalt, that effectively obscures the Sierra Madre faults between these two canyons. The escarpment of the Cucamonga fault, which forms the south front of the salient, however, is not covered by the landslide.

East of San Dimas Canyon the Sierra Madre zone runs slightly north of east. It is covered by a landslide of Basement Complex for most of the distance to San Antonio Canyon. It crosses San Antonio Canyon near the mouth of Evy Canyon and runs up the north side of Stoddard Canyon. This fault zone, east of San Dimas Canyon, straightens and apparently steepens. The throw east of San Antonio Canyon apparently increases, and probably the principal displacement has been vertical in its eastern part.

The cumulative throw (vertical uplift) along the Sierra Madre zone varies considerably, each salient having been upthrust more or less independently. Judging from the difference in elevation between the bedrock floor at the base of the mountain-front scarp, and the elevation along the top of the scarp, the maximum throw is north of Altadena, where it approaches 5000 feet. The salients north of Glendora and San Dimas do not appear to have been upthrust much more than 2000 feet. It is possible, however, that relatively soft Miocene sediments have been stripped off these blocks since their uplift, reducing the apparent throw.

It can be seen from Plate A, that the south fault of the Sierra Madre zone which faults older rocks against the main body of alluvium, lies about one-half mile south of the main fault zone from Eaton to Dalton Canyon. East of Dalton Canyon this fault is about one mile south of the main zone and diverges widely from it easterly from San Dimas Wash.

One or more faults in each salient between Monrovia and San Dimas canyons are shown on the geologic map, between the mountain-front zone and the outlying fault. These faults are small nearly vertical faults with upthrow on the south. The throw varies from a few feet up to about 200 feet. Apparently they represent some sort of adjustment following overthrusting on the major faults of the zone.

The Cucamonga fault zone is continuous from Dalton Canyon to Lytle Creek. It forms the south boundary of surface outcrops of the Basement Complex. Alluvial surfaces are displaced 10 to 250 feet along this fault. West of San Antonio Canyon the throw appears to be nearly 1000 feet. East of this canyon it increases rapidly, reaching probably a maximum of 4000 or 5000 feet. The fault where exposed at the mouth of Liveoak Canyon is a steep reverse fault, dipping about 78 degrees north. No other exposures were seen. Its comparatively straight trace and large vertical movement suggests that it is a steep fault zone throughout.

The San Gabriel fault zone that runs through the heart of the range forms the second major belt of uplift. Faults of this zone where exposed in two areas, have been found to be steep reverse faults. Hill[1] shows a dip of 60 degrees to the northeast (Dillon fault) on a part of the San Gabriel zone near Big Tujunga Canyon. The fault is exposed again in a road cut where it crosses the north fork of San Gabriel River. Here the strike is N. 84 degrees W.; and dip, 87 degrees N. An old alluvial terrace is faulted down on the south against Basement Complex. North of this fault zone, the range rises 2000 to nearly 5000 feet about the mountain tops on the block to the south. This difference in elevation may well be due to uplift of the northern block along San Gabriel fault zone.

Although it has been suggested that the east and west forks of San Gabriel River follow the fault zone, no well-defined zone of faulting along the river could be found. The river is not straight, and unbroken structures make it impossible to project a continuous fault along the two main forks. The main zone, as shown on the map, lies north of the river and there may be more faults north of that line.

The San Gabriel range is cut along its northeast margin by the San Jacinto, Loma Linda and San Andreas faults. Some uplift has probably occurred along these lines, although the distribution of scarps suggests that horizontal movement has been dominant.

San Bernardino Mountains. That portion of the San Bernardino Mountains lying in the South Coastal Basin is bounded along most of its southwest margin by the San Andreas fault zone. Several thrust faults beginning near the San Andreas fault diverge from it, swinging easterly into the range. These faults probably account for most of the uplift of the range along the south and west sides. Noble[2] has described the western San Bernardino Mountains as:

"* * * essentially a succession of crustal blocks, each of which is tilted north and is raised on the south along a northward-dipping reverse fault. * * * The mass as a whole was raised by compression. Inasmuch as it is composed of massive crystalline rocks the deformation has resulted in reverse faults, shearing, arching and tilting."

Five fault zones are shown on the geologic map (Plate C) north of the San Andreas fault, running easterly into the range. These are the principal lines along which uplift of the southwestern San Bernardinos has occurred. The most southerly of these, the Mission Creek fault that branches from the San Andreas between Devil Canyon and Waterman Canyon, is more typical of the NW.-SE. system, being steep and comparatively straight. Probably there has been considerable horizontal movement on this fault. The Santa Ana fault, that runs through the upper Santa Ana Canyon in the San Bernardino Mountains, is only gently curved and may also have suffered horizontal movement. Like the E.-W. faults along the south front of the San Gabriels, those north of the Mission Creek fault are in general cusp-like with their traces convex toward the south.

The cumulative uplift of the range along the E.-W. faults is in part offset by the northward tilting that has accompanied the faulting.

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[1] Hill, Mason L., *op. cit.*, Pl. 15.

[2] Noble, L. F., Excursion to the San Andreas Fault and Cajon Pass, Int. Geol. Congress Guidebook 15, Sou. Calif., pp. 20–21, 1932.

However, the old mountain-top surface as represented by the even crest-line is 5000 to 7000 feet above the bedrock floor south of the San Andreas fault. This apparently enormous throw is in large part real, but may to some extent be exaggerated by the effect of horizontal shift in bringing low areas opposite high areas.

Santa Ana Mountains. The main elevated part of the Santa Ana Mountains comprises a single fault block of crystalline rocks, uplifted on a series of normal faults of the Elsinore zone along the northeast, and tilted southwesterly toward the Coastal Plain.

The Elsinore fault zone, as described and mapped by Engel,[1] is shown on Plate A. Unlike most fault zones of the NW.-SE. system, the faults of the Elsinore zone are, according to Engel, almost exclusively normal faults. The complicated pattern shows that no single fault runs continuously through the zone.

The southwest slope of the range is flanked by Cretaceous and Tertiary sediments that dip at moderate to gentle angles toward the Coastal Plain. Broad folds roughly paralleling the axis of the range comprise the foothills along the southwest base of the mountains.

The mountains are cut off on the north by the Whittier fault that swings westerly from the Elsinore zone. The Puente Hills, lying north of this fault, are not comparable in height to the Santa Ana Mountains. The structure is also different, compression folds predominating there.

The total throw of the Elsinore zone is not measurable from the data at hand, but the later Quaternary uplift, estimated from the height of the dissected fault scarp, is about 2000 to 4000 feet.

GROUND WATER IN THE NONWATER-BEARING SERIES

The Nonwater-bearing series, which is made up of the relatively impervious formations that underlie and surround the ground water basins, differs from the Water-bearing series essentially in two respects: (1) the Nonwater-bearing series is for the most part relatively impervious, and therefore stores comparatively little water, which it yields to wells very slowly; and (2) where pervious beds or zones occur, the movement of ground water and recharge from surface outcrops is generally so restricted by faults, structural position, or physical character of the materials, that supplies obtained from such beds or zones are too limited, and of too uncertain quality and permanence, to be comparable to ground water supplies in the Water-bearing series.

Several types of openings occur in the Nonwater-bearing series, the principal ones being: (1) original interstices in porous beds of the sedimentary rocks; (2) interstices in the weathered soil mantle; (3) fault and joint openings below the surface (including openings along bedding planes and planes of schistosity); and (4) openings caused or enlarged by solution of the country rock.

In most places both the sedimentary and crystalline rocks are so tight that they yield very little water to wells, and consequently are of no value except for domestic or stock watering purposes. Since these formations drain very slowly the ground water is generally compara-

[1] Engel René, Geology of the Southwest Quarter of the Elsinore Quadrangle (abstract) Geol. Soc. Am. Bull. 43, p. 225, 1932, and unpublished geologic map, by personal communication.

tively near the surface and the water table is high under the hills and low in the canyons. In the deeper canyons and in many places in the hills, the water table intersects the surface and water seeps out as springs or is consumed by evaporation and transpiration. Surplus water in the Nonwater-bearing series, not utilized by transpiration or evaporation, flows into the ground water basins. Underflow into these basins from the Nonwater-bearing series is relatively small, but nearly constant.

In places pervious strata or fault zones in the Nonwater-bearing series yield water freely to wells. However, in most cases such production is short-lived because of small storage capacity and inadequate recharge.

BASEMENT COMPLEX

The Basement Complex, composed as it is of rocks that crystallized from liquid magmas or recrystallized from old sediments, contains no original pore spaces. The openings have all developed since formation of the rocks. Below the soil mantle the openings are principally joint fractures, cracks along planes of schistosity, and faults. Joint cracks are confined chiefly to the zone of weathering and die out rapidly with depth. Cracks along planes of schistosity diminish in number and become tighter below the weathered zone, but fault fractures continue downward and form the principal openings for deep zone circulation of ground water.

With the exception of the region south of Riverside, the Basement Complex outcrops only in the mountainous areas. Consequently the slopes are generally steep; unweathered rock outcrops in the canyon bottoms and lies near the surface beneath the canyon sides. In many areas, however, faulting has closely fractured the Basement Complex. These fractures are especially prominent in schistose types.

In considering the occurrence and movement of ground water in the Basement Complex, the rocks fall into two groups, the massive crystalline rocks and the schistose and banded gneissic rocks.

The massive rocks, which are principally granitic, contain very little ground water except in fault or joint planes, and in most areas jointing, due to weathering, practically dies out within 50 feet of the surface.

The ground water is all derived from precipitation upon the Basement Complex surface. It percolates downward through the weathered zone and along faults, issuing as small springs in side ravines high above the main canyon bottoms. Water occurs at or very near the surface in all the main canyons. This indicates that the granitic rocks are too tight to drain freely down to the levels of the main canyon bottoms, and consequently, even in areas of high relief, the water table follows the surface and lies at or only a few feet beneath it.

Tunnels several hundred feet long in massive crystalline rocks seldom produce continuous flows of more than one or two miners inches, and wells produce only domestic supplies.

In the region south of Riverside where the relief is low, these rocks are deeply weathered and in the low areas the water table is near the surface and ground water occurs in the thick residual soil mantle and in the weathered bedrock below. Even these supplies are relatively small, however, and not sufficient for irrigation purposes.

Fault zones in these rocks, though inclined to be clayey, form practically the only zones that carry water at depth. Flows of several miners inches are sometimes obtained when these zones are penetrated in tunnels, but the stored water generally drains out in a short time and the flows drop to fractions of their initial production.

The schistose rocks, which include the banded gneisses, schists, and slates, though relatively poor in ground water, are better than the massive crystallines. Rocks of this type outcrop principally in the Santa Monica, Santa Ana and San Gabriel mountains, but scattered outcrops occur elsewhere. Weathering, faulting and solution all tend to open cracks along the planes of schistosity, and consequently the movement of ground water in schistose rocks is controlled to a large extent by their structure. As in the granitic rocks, springs in the schistose rocks are generally small and apt to appear high above the canyon bottoms in small ravines. Usually they are merely moist spots or trickles marked by heavy growth of trees. A number of tunnels have been driven into these rocks along the southern base of the San Gabriel and San Bernardino mountains, from which small continuous flows are obtained. The water seeps into the tunnels from cracks and crushed zones, generally along planes of schistosity. Experience in driving tunnels into these banded crystalline rocks has shown that water pockets exist in crushed zones with water stored under rather high heads. As the stored water drains, the flow gradually diminishes. Permanent flows from tunnels several hundred feet long seldom exceed two or three miner's inches.

The unweathered Basement Complex is in general tight and practically dry. A large part of the tunnels driven to secure water have been failures, but where zones of faulting exist, like those along the southern base of the San Gabriels, tunnels driven in favorable locations to tap these fault zones have often proven successful.

PRE-OLIGOCENE SEDIMENTS

The Cretaceous and Eocene sediments are for the most part cemented sandstones and hard conglomerates with interbedded clayey and limey shales. They are practically impermeable throughout most of their extent. Their ground water is derived for the most part directly from precipitation upon the outcrops.

Cretaceous beds outcrop only in three areas within the South Coastal Basin, in the Simi Hills, the Santa Monica Mountains and the Santa Ana Mountains. In most cases the original pores have been closed by compaction and cementation, making these rocks similar in water-bearing properties to the Basement Complex. Widely spaced jointing, cracks along planes of bedding, and faults furnish practically the only avenues for percolation of ground water, and most of these die out with depth. Small springs occur throughout the formation which generally stands in high relief. These springs yield little water and generally occur between beds of different lithology.

Little attempt has been made to develop water in the Chico formation but it seems probable from its indurated character that wells would yield only small domestic supplies.

The Eocene beds, like the Cretaceous, are generally highly indurated and contain practically no water except in secondary openings developed by weathering or faulting. The outcrops are limited and occur in mountainous areas.

In the Santa Monica Mountains, Martinez beds are not differentiated from Chico beds. In the Santa Ana Mountains, the Martinez is a compact well-cemented sandstone containing considerable clayey shale. South of Corona between Temescal Wash and the Santa Ana Mountains, coarse white massive sandstone beds with occasional gravel streaks occur, which probably would produce sufficient water for domestic purposes.

The Tejon outcrops are limited to two areas in the Santa Ana Mountains, one, a short distance south of the Santa Ana River and the other, along the north side of Santiago Creek. The Tejon sandstone is characteristically creamy-yellowish to white with buff streaks, and although well indurated in the main, does contain beds of loose clean sand which if penetrated by wells below the water table would produce fair quantities of water. However, the outcropping areas are so small and water-bearing beds so isolated that the water supply available to any well would be very limited and probably slow to recharge.

Oligocene (?) and Lower Miocene Sediments.

The Sespe (?) red conglomerates which occur beneath the known Vaqueros beds, both in the Santa Monica and Santa Ana Mountains, are probably at least in part continental. They are poorly bedded, compact, and more or less decomposed. In large part the conglomerates are clayey. Some of the sandy and gravelly beds are firmly cemented, but others are not. It seems probable that these red beds below the water table might be comparable in water-bearing properties to the poorest areas of Quaternary alluvium. The formation is not extensive, however, and therefore unimportant as a possible source of water.

The typical Vaqueros and Topanga beds are well-cemented sandstones and conglomerates. They are similar in water-bearing properties to the older sediments. Both the conglomerates and sandstones are in most cases too well indurated to produce any water from original openings, but contain a little water in cracks. There are occasional beds of rather clean loose sand in the Topanga, however. Trees and springs in ravines show that the water table is near the surface.

In both the Santa Ana and Santa Monica mountains, these beds, which outcrop in the hills adjacent to the ground water basins, dip under the basins and are encountered in deep wells that penetrate the alluvium. Small flows of warm or hot water may be obtained from such wells, but ordinarily not in quantities sufficient to justify the deep drilling required. Two such wells, drilled near Ventura Boulevard about one mile east of Reseda Boulevard near the southern edge of San Fernando Valley, developed small flows of warm mineralized water from beds of probable Topanga age. The water table stands higher than that in the overlying alluvium and apparently have no connection with it.

The ground waters near the surface are derived from rainfall upon the outcrops. These waters are fresh and of comparatively good quality, but deep zone waters encountered occasionally in wildcat oil wells are probably connate. They are generally hot and salty. Shallow wells which encounter ground water near the surface may supply water for stock raising or domestic needs, but would be inadequate for irrigation purposes.

Miocene Volcanics.

Throughout the Topanga and parts of the Puente and Modelo formations, volcanic flows, breccias and tuffs, associated with intrusive sills and dikes, are common. Basalts and andesites (dark colored rocks) are the most common types, but more acid (light colored) types, such as felsite and dacite, occur in some areas.

The flows and sills, like the Basement Complex, are crystalline rocks, but the breccias and tuffs are clastic deposits with high original porosity.

Jointing due to shrinkage, that accompanied cooling and subsequent deformation of the solid lavas, has shattered many of them to such an extent that they have become more or less permeable. Breccias and tuffs which are not completely cemented are also permeable.

Ground water in the lavas originates in most cases from rainfall and percolation from streambeds in the areas of outcrop. In some places, however, lavas lie beneath ground water basins, from which they are supplied.

Where lavas outcrop over considerable areas, as they do in the eastern part of the San Jose Hills, springs and other evidence of a high water table are lacking in the hills. Springs are common, however, along the base of lavas where they overlie impervious beds.

Two wells, drilled in the vicinity of San Dimas through tight alluvial beds into underlying volcanics, have obtained small irrigation supplies from the volcanics. Several other wells in the same district, however, have been drilled into the lavas without success. It does not seem probable that wells favorably located will produce more than five to ten miner's inches from the volcanic rocks, and in most cases less.

It is possible, however, that where lavas lie below the water table and yet within reach of shallow wells, good domestic supplies, and in some cases sufficient water for local irrigation purposes, may be obtained.

Distribution of the volcanics, which generally occur in comparatively thin beds and often in positions unfavorable for storage of water, limits the usefulness of these rocks as ground water reservoirs in the South Coastal Basin. Supplies available from this source are negligible when compared with those of the ground water basin. Consequently, they are not considered to be a part of the Water-bearing series.

Upper Miocene Shales.

The Puente and Modelo shales, which outcrop over a large part of the intermediate hills, are characterized by moderate to rather low relief with comparatively gentle slopes. The soil mantle is but a few feet thick and very clayey. The weathered zone is not extensive.

The original pore spaces in the shales have in large part been closed by cementation, but where they still exist they are too small to permit percolation of water through them. In the main these shales are brittle thin-bedded indurated siliceous deposits, with calcareous and gray silty facies. They are very incompetent, and where they have been subjected to deformation are contorted and badly crushed. The brittle varieties crack into small pieces and what little water is contained in the shales below the weathered zone, occurs mainly in the numerous crushed zones in the hard siliceous and calcareous varieties.

Ground water in the shales originates from rainfall on the areas of outcrop, and since the formation is tight the water table conforms rather closely to the minor topographic features and lies near the surface.

The shales are both too tight and their structure too badly broken by faulting and folding to permit percolation through the beds into deep zones. Consequently percolation is local, and dependent upon arrangement of the surface drainage system. The ground water seeps downward through cracks and comes to the surface in the small ravines, where it feeds rather scant growths of sycamores, oaks and occasional willows. Springs in the ravines and on the hillsides are not uncommon but are very small, and in most cases are marked merely by moist areas. Surface streams originating in the shales are practically unknown during the dry season. The shale in places supports a rather sparse growth of native black walnut trees, which probably derives its water from silty or fine sandy saturated beds the pores of which are too small to permit drainage by gravity.

Production of water from the shales is very limited and is confined almost entirely to development of springs and shallow wells for the purpose of watering stock. The water is of poor quality and in many cases not fit for human consumption.

Upper Miocene Sandstones and Conglomerates.

Modelo and Puente sandstones with conglomerate facies outcrop over a large part of the intermediate belt of hills, where they are interbedded with shale members. Their outcrops are more bold and their slopes inclined to be steeper than the shale, but otherwise their topography is similar.

The sandstones, as a rule, are rather massive and well-cemented. At the surface their weathered outcrops are yellowish-brown with prominent partings along contacts between beds, and are cut by widely spaced joints. The unweathered sandstone is gray, and generally being well-cemented has low porosity and low permeability. Unlike the shales, the sandstones are competent and do not crush easily. Consequently for the most part the unweathered sandstones are practically impervious. On the other hand, locally there are sandstone and conglomerate beds that are practically uncemented or poorly cemented, and these beds permit the storage and movement of ground water.

Ground water near the surface in the sandstones, like that in the shales, originates from rainfall. Except where pervious beds outcrop, the water table in the sandstones is near the surface and supports tree growth in most of the ravines. Occasional small springs occur, but there are no perennial streams that originate in the sandstones.

Although the greater part of the Puente and Modelo sandstones are comparable to the shales in their lack of water-bearing properties, outcrops of pervious sandy and gravelly beds, together with production of water from several deep wells show that the sandstones are not impervious throughout. Several wells near the Santa Ana River north of Corona penetrate probable Puente sandstones to depths of nearly 1000 feet; these wells produce relatively small quantities of warm sulphur water. It seems probable, however, that if permeable beds are tapped below the water table, yet near their outcrops, limited supplies of water of good quality will be obtained.

The presence of many faults and enclosed structures together with the lenticular nature of the permeable beds has prevented deep circulation and replacement of the original (connate) salt waters of the formation by fresh surface water. Deep oil wells invariably encounter hot salty water in upper Miocene formations.

It seems probable, therefore, that the possible development of water supplies in the sandstones and conglomerates of the Puente and Modelo formations is limited, not only by the scarcity of permeable beds but also by the local source of recharge in most cases from rainfall upon the outcrops, and by the comparatively small storage space above the salty connate water.

The Upper Miocene continental conglomerates and sandstones of the Cajon Pass region, especially in their upper part, are poorly consolidated and where these deposits dip down below the water table the water-bearing properties are probably comparable to those of Quaternary alluvial deposits.

Pliocene and Lower Pleistocene Deposits.

Pliocene and Lower Pleistocene deposits underlie the Water-bearing series beneath the Coastal Plain, and beneath portions of San Fernando, San Gabriel and Upper Santa Ana basins. They outcrop at various places in the hills around the margins of the basins, and the pervious beds in the upper parts of the deposits form a part of the Water-bearing series of the ground water basins.

These beds, throughout a large part of the region, are composed of clayey and silty shales and soft fine sandstones, in which the pore spaces are too small to permit appreciable movement of ground water through them. However, poorly consolidated marine sandstones and conglomerates with high porosity and high specific yields are present. Although the upper beds of this type are considered to be a part of the Water-bearing series, there are many similar beds, separated from the upper beds by thick shale bodies, that belong to the Nonwater-bearing series.

The finer sediments of the Pliocene and Lower Pleistocene, though somewhat less indurated than the older sediments, have the same general effect upon the water table where they outcrop in the hills. Occasional small springs and other evidences of water near the surface are seen in the ravines which cut the deposits.

The ground water contained in the pervious beds near the surface is derived principally from rainfall and percolation from streambeds into the deposits at their outcrops. The pervious beds, where cut by canyons, drain down to the level of the canyon bottoms. Below the canyon bottoms the surface waters percolate downward and gradually seep through less pervious beds into the ground water basins, or if effectively sealed by impermeable barriers, remain static.

Previous beds beneath the ground water basins, but separated from them by shale bodies, generally contain hot connate waters or diluted connate waters too high in dissolved solids to be used for domestic or irrigation purposes. The quality of the water becomes poorer below the outcrops also, and consequently ground water supplies in pervious beds in the hills have limited storage capacities which generally extend to depths of only a few hundred feet. Since these beds outcrop as lenses between finer deposits and have both small sources of supply and limited storage capacities, they are unimportant sources of ground water supply even though locally wells may for a short time produce amounts comparable to wells in the ground water basins.

The upper pervious beds of the Pliocene and Lower Pleistocene deposits that form a part of the Water-bearing series are described with the later Quaternary deposits, in Chapters IV-VII, under the detailed descriptions of the various basins.

CHAPTER III

THE SEDIMENTS WHICH PRODUCE GROUND WATER IN THE SOUTH COASTAL BASIN

In Appendix I the results of experimental work to determine the water-yielding capacity of different types of sediments was discussed. These results are, in the present chapter, applied to typical fresh-water-producing sediments of the South Coastal Basin. Their general geographic and geologic distribution are indicated, the properties which pertain to their water-yielding capacity are discussed fully, and water yield values are assigned for the different types and for the variations between types. The method used to apply these values to well log data for computation of underground storage capacity of the basins is outlined.

The water-bearing properties of old crystalline rocks and the indurated folded sediments that form the hills and mountains around the basins were discussed in Chapter II. The sediments now considered are, in the main, Upper Pleistocene and recent deposits, brought down by streams that drain the mountainous areas of crystalline rocks, with lesser amounts from streams that drain hills and mountains composed of folded and indurated sediments. On the coastal plain, marine deposits are interbedded with the alluvial deposits.

In order to clarify the discussion the properties of the sediments as they were originally laid down will be described first, followed by a discussion of the changes that have since altered the sediments and the effect of this alteration upon the water-yielding properties.

PROPERTIES OF THE ORIGINAL DEPOSITS

Determination of the water-bearing properties of the original, or unaltered deposits offer a basis for classification of the complex series of partly consolidated sediments of the freshwater-producing horizons of the South Coastal Basin. Therefore, although the unaltered sediments occur only at the surface, they have been studied in detail and their water-yielding capacities form the basis for estimating the specific yields of their various partly consolidated products.

In order to classify the materials in such a manner that their specific yield values could be used for computing storage capacity, it was necessary to make a classification that would apply the results of experimental work to the materials as logged by well drillers. A study of more than 5000 water well logs in the South Coastal Basin showed that the well drillers recognized clearly three classes of materials, namely: sands, gravels, and clays. In fact, some drillers use only these three terms in their logs. All other terms are modifications of these three classes, and although different drillers differ widely in their modifications, their basic separations appear to be consistent and reliable.

This entire study of water-bearing properties has been made with the idea of establishing reasonably definite values for the three main classes of materials, to determine the probable limits of variation for each class, and then to apply these values with their variations in the most reasonable manner possible to the modified classifications encountered in the different well logs.

Both continental and marine sediments were included in the study, and the properties of the original deposits of each are discussed separately under three main groups: the gravels, the sands, and the clays.

The Continental Sediments.

The Quaternary series of continental sediments in the South Coastal Basin is composed essentially of alluvial cone deposits that have accumulated in the four major structural basins of the area since the beginning of the great Pleistocene deformation. They are the materials transferred by running water from elevated areas to depressed areas as the direct result of increasing relief produced by deformation.

Locally, special conditions have given rise to wind-laid deposits and swamp or lagoonal deposits but such areas are not widespread.

Over most of the region the deposits have been laid down by the same intermittent streams that now occasionally bring debris from the mountain canyons and spread it upon the cone surfaces. The deposits have all the characteristics of typical alluvial cone deposits, and their properties as determined in this investigation are probably best applied to deposits of this nature.

Alluvial Gravels

Alluvial gravels are practically the only materials deposited upon the upper slopes of the alluvial cones. Their general size distribution has been described frequently [1] and is well known. However, it seems that a rather critical analysis of size distribution and the factors controlling it is pertinent to the study of water-yielding capacity, and the subject will therefore bear some discussion here.

Since the principal streams of the South Coastal Basin in their headwater areas flow through deep, rugged, steep gradient canyons cut in crystalline rocks, the material supplied to the streams is very coarse, and coarsest where the relief is greatest. The small streams have short steep gravel cones, in contrast to the long gently sloping cones of the larger streams. The gravels at the heads of these steeply sloping cones are often coarser than those at the heads of the larger cones.

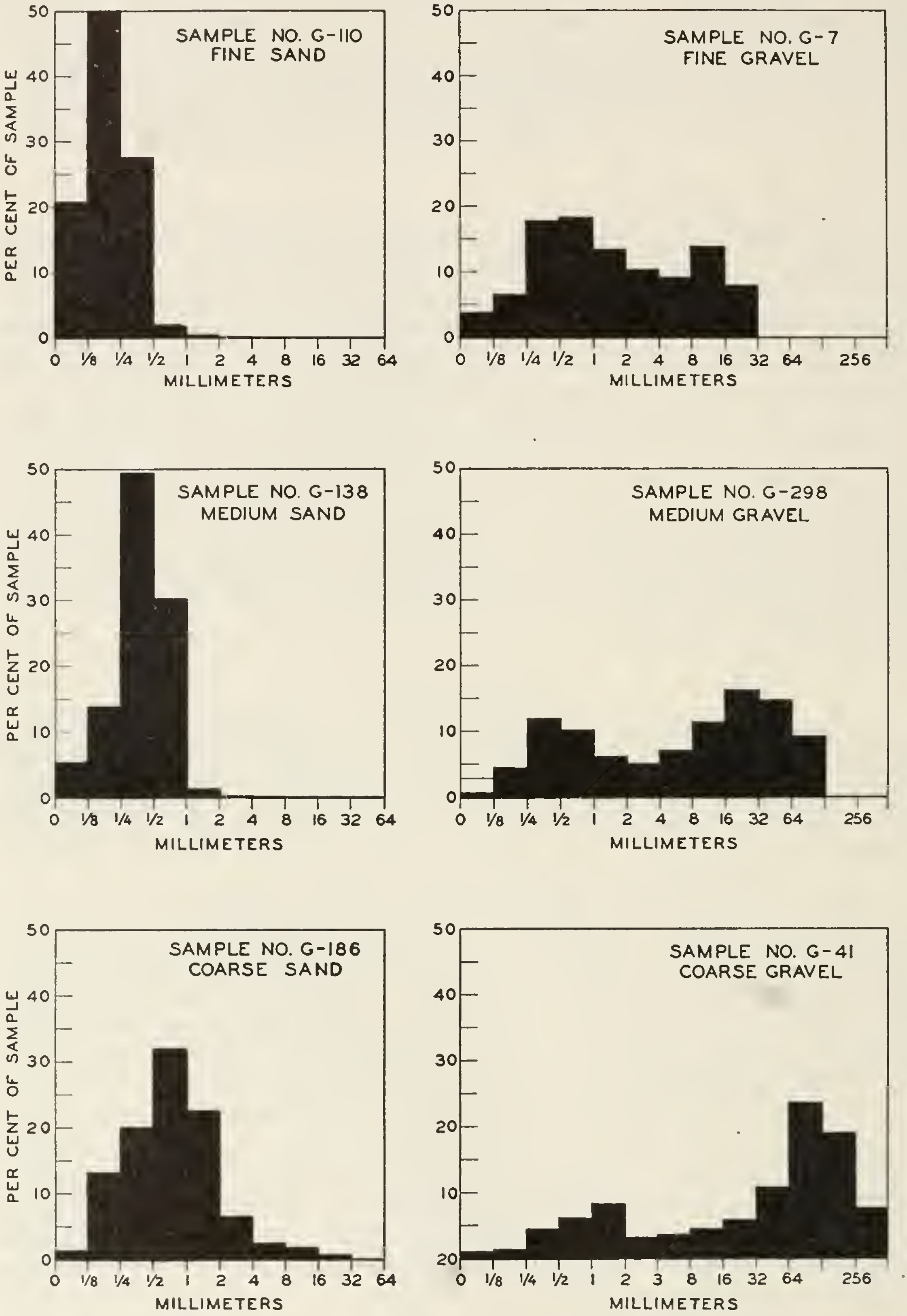
The principal factor that controls the maximum size distribution of gravel upon the cones is velocity of stream flow. It has been shown [2] that in stream beds of different parts of the world, slope is the most important factor controlling velocity, and furthermore, that slope is the dominant factor controlling size of particle, even masking the effects of increased volume of water from tributaries. The coarsest material occurs on the steepest slope.

On free alluvial surfaces it is doubtful whether the slope determines the maximum size of material deposited or whether the maximum

[1] Johnson, Harry R., Water Resources of Antelope Valley, California. Water Supply Paper 278, pp. 27–29, 1911.

[2] A. O. Woodford and Edward Taylor, Longitudinal Profiles of Streams. (Abstract) Bul. Geol. Soc. of America, 1933 (advance sheets for 1934 volume).

PLATE IX



MECHANICAL ANALYSIS-GRAPHS
OF
TYPICAL SANDS AND GRAVELS IN SOUTH COASTAL BASIN
SHOWING
SIZE CLASSIFICATION OF SAMPLES

size determines the slope. At any rate, the two are in equilibrium and volume of stream discharge is of secondary importance.

The small cones have steeper slopes and larger boulders at their apices than the large cones but are more sharply concave downstream, and at distances of a few miles from their canyon mouths they have lower slopes and finer gravels than the larger cones. This relationship is shown in Table 2, which gives the headwater areas, surface slopes and relative sizes of coarse material from various points on several alluvial cones along the base of the San Gabriel Mountains.

TABLE 2

SIZES OF FRAGMENTS ON FANS[1]

Fan	At fan apex, inches	Slope angle	2½ miles from apex, inches	Slope angle	5 miles from apex, inches	Slope angle	Area of watershed in square miles
Lytle	87	1° 40′	54	1° 35′	30	1° 00′	47.9
San Antonio	69	2° 40′	54	1° 58′	26	1° 30′	26.2
Cucamonga	90	2° 45′	30	2° 20′	22	1° 25′	10.6
Day	112	5° 45′	21	2° 30′	13	1° 05′	4.9
Deer	157	9° 05′	19	2° 33′	8	0° 59′	3.4

NOTE: Each value given is the median of the lengths of the ten largest fragments found in a distance of 50 yards along the wash.

The absence of sand or clay deposits upon the upper slopes of the cones is striking. The deposits there are chiefly poorly sorted gravel deposits which are unbedded or indistinctly bedded. A consideration of the conditions under which deposition by the intermittent streams occurs may offer some explanation for the unsorted character of the coarse gravel deposits.

During periods of flood flow the boulders and cobbles are rolled along the bottom of the channel, and the finer material is carried in suspension. In the canyons the coarse rolled material is greatly in excess and hence accumulates on these steep upper slopes of the cone. Some fine material is trapped in the interstices of the coarse material, but in the main the load in suspension during flood is probably carried down over the steep gravel-covered slopes and out onto the flatter part of the cone. The material deposited from suspension as the flood flow diminishes occupies the interstices of the coarse material, so that practically no sand is left in the channels nor in the deposits beneath the upper cone surfaces. Typical mechanical analyses of these gravels are shown in Plate IX. The two maxima of these curves are characteristic of the alluvial gravel samples taken in this region. Probably the coarsest maximum represents the materials rolled and bounced along the channel bottom, and the finer percentage maximum represents the material deposited in the interstices between the boulders and cobbles from suspension.

Downstream upon the cone with decreasing slope the maximum size of particles decreases until deposits of sand appear and gradually become abundant on the cone. Far out in the valley bottoms where the slopes become very gentle and the cones coalesce to lose their identity silts and clays are deposited upon the surface, sand fills the channels,

[1] Reprinted from: R. Eckis, Alluvial Fans of the Cucamonga District, Southern California, (1928) Tables I and II, pages 233, 234.

and the only gravel deposited lies in the channel bottoms beneath the sand.

The size distribution is directly related to water-yielding capacity of the gravels, and a knowledge of it is, therefore, a valuable aid to the estimation of ground water storage capacities in the alluvial deposits.

The water-yielding capacity of gravel has, from the results of 164 samples, been estimated to vary between a lower average limit of about 13.6 per cent and an upper average limit of about 26.5 per cent. This specific yield of gravel is the difference between its specific retention and its porosity, as defined on page 227. The specific retention depends directly upon the size of particles and varies roughly with the total surface area of the individual particles (pages 243–246).

PLATE X

Detail of gravel bank, upper part of San Gabriel Cone near Foothill Boulevard.

The factors which determine porosity are: (1) the shapes of particles; (2) the distribution of sizes, or sorting; and (3) the arrangement or packing of the particles.

On free surfaces of deposition such as those of the South Coastal Basin, these factors which determine porosity are dependent upon the competence of the streams that transport and deposit the materials. The velocity of flow of a stream determines the size of particles that it is competent to transport. Therefore, the size of particle deposited, being a measure of the competence of the stream, should also be a measure of the porosity of the materials deposited.

The Maximum 10 per cent Grade Size. In order to determine the relationship between maximum size of particle, sorting and porosity, the results of mechanical analyses of more than 200 dug gravel and sand samples, the porosities of which had been measured (see appendix), were studied. The samples were classified according to their relative coarseness. As an index of coarseness the maximum 10 per cent grade size was used, that grade size being the one in which the cumulative total, beginning with the coarsest material reaches 10 per cent of the total sample. In most cases where the maximum 10 per cent exceeded 16 millimeters, the smallest size in it was found to be one grade size smaller than that of the absolute maximum particle. Occasionally, in very coarse samples it was found to be the same grade size as that of the maximum-sized particle. The maximum 10 per cent size in coarse gravels was also found to be generally one grade size larger than that of the dominant (by weight) coarse size, although this condition did not always exist.

In samples where the maximum 10 per cent grade size was less than 16 millimeters it was found to be generally two or three sizes below the absolute maximum grade size, and two or three sizes above the grade size dominant by weight.

Table 3 shows the average ratio deviation (page 233), a measure of sorting, and the average porosity for the samples, classified according to maximum 10 per cent grade size. The ratio deviation increases and the porosity decreases as the materials become coarser.

TABLE 3

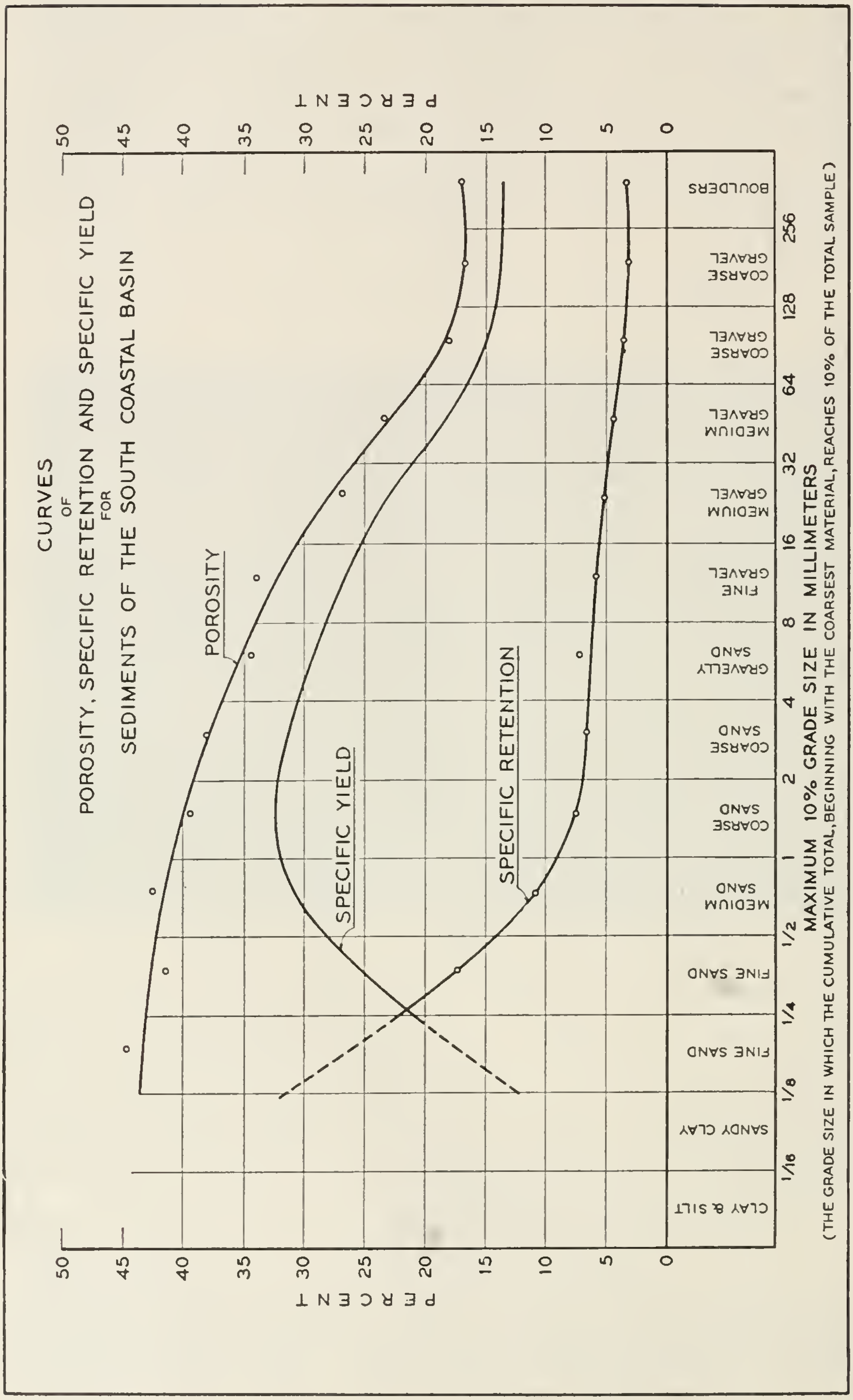
RELATION OF POROSITY AND RATIO DEVIATION IN SANDS AND GRAVELS TO SIZE

Maximum ten per cent grade size	Sand, ½–8 mm.	Fine gravel, 8–16 mm.	Medium gravel, 16–64 mm.	Coarse gravel, 64–256 mm.	Boulders, 256+ mm.
Porosity, per cent	38.6	33.8	24.8	17.4	17.0
Ratio deviation	2.77	4.43	6.97	8.12	10.22

Typical mechanical analysis diagrams of coarse gravel, medium gravel, fine gravel, and sand are shown on Plate XI. The relationship between maximum size and sorting is clearly shown by these diagrams. The coarse gravel diagram shows two well-defined percentage maxima with the coarse maximum greater than the fine maximum. In that diagram of the medium gravel, the two maxima are closer together and there are fewer grade sizes represented. This diagram shows better sorting than the first. The diagram of the fine gravel shows still fewer grade sizes and the two maxima close together, with the coarser much less pronounced than the finer. In the typical bell-shaped sand diagram there is but one maximum. Perfect sorting is approached in this type of diagram as the dominant size approaches 100 per cent of the sample. Although these analyses are considered to be typical of their respective classes of sediments, many and complex variations from them occur. Consequently, the maximum 10 per cent grade size is only a rough measure of the mechanical composition of the sample, and is applicable only when it represents an average value.

Now assuming that on similar alluvial cones the shape of particles and degree of packing are minor variables between gravels of equal coarseness, it should follow that the maximum 10 per cent grade size is a measure of the porosity of the gravel. The gravel samples taken on Santa Ana, Lytle, San Gabriel, Tujunga, and Pacoima cones were therefore selected and their porosities were plotted against the maximum 10 per cent sizes. Samples from the smaller cones were grouped

PLATE XI


CURVES
OF
POROSITY, SPECIFIC RETENTION AND SPECIFIC YIELD
FOR
SEDIMENTS OF THE SOUTH COASTAL BASIN
POROSITY
SPECIFIC YIELD
SPECIFIC RETENTION
PERCENT
0
5
10
15
20
25
30
35
40
45
50
CLAY & SILT
SANDY CLAY
FINE SAND
FINE SAND
MEDIUM SAND
COARSE SAND
COARSE SAND
GRAVELLY SAND
FINE GRAVEL
MEDIUM GRAVEL
MEDIUM GRAVEL
COARSE GRAVEL
COARSE GRAVEL
BOULDERS
1/16
1/8
1/4
1/2
1
2
4
8
16
32
64
128
256
MAXIMUM 10% GRADE SIZE IN MILLIMETERS
(THE GRADE SIZE IN WHICH THE CUMULATIVE TOTAL, BEGINNING WITH THE COARSEST MATERIAL, REACHES 10% OF THE TOTAL SAMPLE)

and plotted in a similar manner. No consistent difference was detected between values on the two curves, and they were therefore combined to form the curve that appears on Plate XI. It is clear from this curve that the porosity increases from about 17 per cent with miximum 10 per cent size at 256 to 512 millimeters to about 34 per cent with maximum 10 per cent size at 8 millimeters, the lower size limit of gravel.

Values for 164 samples were plotted for the gravel portion of the curve, and the average deviation from the mean for any given grade size is rather large, but largest for the sizes with the fewest samples. This shows that these curves can not be used to predict the porosity of a single sample the maximum 10 per cent grade size of which is known. It is obvious also from the widely different results obtained from porosity samples at the same location, that a single sample the porosity of which is known does not give a measure of the average porosity of the gravel bed or formation. Consequently, it is necessary to average the results of many samples in order to obtain values representative of true conditions on the cones. Classification of the porosities by size of particles appears to be the most practical means of applying the results of sampling to the distribution of gravels on the cone. The maximum 10 per cent grade size was chosen because it generally is the grade size midway between that of the coarse dominant weight size and that of the absolute maximum size, and can therefore be estimated for gravel beds in the field. It was used also to compare the gravel samples obtained during the drilling of wells with those dug from the surface deposits.

The Surface Factor and Specific Retention. The relation of specific retention to size of particle is discussed fully on pages 243–246, and a curve shown (Plate XXIII) from experimental results, plotting diameter of particle with mean surface (surface factor) against weight per cent of water retained. Although this curve probably does not give an accurate specific retention for all porosities, the variation from it in the case of any one gravel sample probably does not alter the computed per cent yield value by more than one per cent of its volume. The accuracy of the curve for gravel retentions is, therefore, thought to be within the limits of other uncertainties and has been used to compute the specific yield values for gravel samples whose porosities were measured.

The Specific Yield Curve. Since both the specific retention and the porosity have been shown to vary with size, the computed specific retentions of the individual samples were averaged for each maximum 10 per cent grade size and plotted on the graph (Plate XI). The measured porosities were averaged and plotted in like manner. Values on the specific retention curve were subtracted from corresponding values on the porosity curve to obtain the points through which the specific yield curve was drawn. The specific yield curve gives the average yield value for gravels of which grade sizes of maximum 10 per cent of particles are known approximately. This curve can not be used to predict the specific yield of an individual sample. If coarse gravels are considered to be those with maximum 10 per cent grade sizes greater than 64 millimeters, the three grade sizes represented give an average specific yield of 14.1 per cent for coarse gravel. If medium gravel be considered to occupy that part of the curve with maximum

10 per cent between 16 and 64 millimeters, the two grade sizes represented give an average specific yield of 20.6 per cent for medium gravels. If gravels the maximum 10 per cent size of which is 8 to 16 millimeters be considered fine gravels, the average specific yield of fine gravel is 26.5 per cent.

Application of the Specific Yield Curve to Surface Gravels. The specific yield values for the gravel samples when plotted on a map show a trend toward higher yield with increasing distance from the cone apices, but the variation is erratic and not consistent with the uniformly diminishing slope and size of particle downstream. Inspection of the maximum 10 per cent sizes of those samples show that they do not decrease uniformly downstream, but rather decrease in an erratic manner, much as the yields increase. In short, it can be seen that in taking samples of coarse gravels it was impossible to get a sample at any one location that truly represented an average yield value for the gravels of that part of the cone.

In view of the concordance shown to exist between maximum size and specific yield, it was thought that better estimates of gravel yield could be made by using the specific yield curve (Plate XI) to determine a yield value for given maximum 10 per cent sizes, the maximum size distribution upon the cones then being estimated from field study and comparison of stream discharges and slopes of the cones.

The gravel samples used to draw the specific yield curve were all collected at or near the surface of the cones but not from the beds of the present washes. They therefore represent the practically unaltered permanent gravel deposits. Values from this curve were not applied directly for storage capacity computations but were slightly modified as explained later (pages 109–110) to account for changes due to burial. The modified values were applied to the fresh, loose gravels reported in well logs.

The lack of stratification near the cone apex simplifies the application of the specific yield curve to these deposits, for the maximum 10 per cent gade size is generally relatively constant in these massive deposits at a particular locality. Down the cone, however, as the average maximum 10 per cent grade size decreases, stratification improves, and where the coarsest gravels are medium gravels (maximum 10 per cent sizes from 16 to 64 millimeters) it becomes necessary to estimate the average maximum 10 per cent grade size for the alternating strata of medium and fine gravels. At first glance it would seem that the average specific yield should rise sharply in passing from the upper region of relatively unbedded coarse materials into the area of better stratified medium gravels. The effect produced by increased stratification down the cone, however, is usually partly or entirely offset by the more gradual decrease of slope and maximum size distribution with increasing distance from the cone apex. Down the cone it finally becomes impossible to determine the average coarseness of the gravels from surface deposits, for on the relatively flat outer parts of the cone, the gravel beds are obscured by sands which fill the channels and cover the surface.

Application of yield values for unaltered gravels to the complex series of altered materials that occur within the basins is described in detail under "Methods used for Computation of Storage Capacity," pages 112–114.

Alluvial Sands

The coarse alluvial sands grade indistinctly into fine gravels, and the fine sands into silts. According to the Wentworth[1] scale, grains from one-sixteenth millimeter diameter to 2 millimeters in diameter are classed as sand. In applying this classification to the South Coastal Basin sands, which contain several grade sizes, any sample the maximum 10 per cent size of which is between 8 millimeters and ⅛ millimeter is considered to be sand. In these samples there is seldom more than 20 per cent of the material coarser than 2 millimeters.

Although coarse sands grade into fine gravels, the typical sand has one characteristic feature that makes it essentially different in mechanical composition from the alluvial gravels. This difference is shown by the mechanical analysis. In Plate IX the double percentage maxima of the gravel analyses are replaced by a single percentage maximum in sand analyses. This means that the sand is better sorted, and the direct result is that the sand has a higher and more uniform porosity than the gravel.

Although the sands and their soil derivatives that cover a large part of the lower slopes and flat parts of the alluvial basins are less abundant beneath the surface, they occur there in considerable quantity, and have an important influence upon the storage capacity of these areas.

The porosity curve for unaltered alluvial sediments shows that the average porosity of sands increases only slightly as the maximum 10 per cent size decreases, the average for 4–8 millimeter sizes being 35.2 per cent and the average for ¼–½ millimeter sizes being 42.7 per cent. Furthermore, the average deviation from the mean for each grade size is much less than that for the gravels. The sand samples from large streams were grouped and compared with those from smaller streams; the average porosity for the large stream sands was 39.1 per cent, and for the small stream sands was 39.7 per cent. There does not seem to be a significant difference between the two.

The specific retention, in the case of fine sand, becomes a more important variable than porosity. The curve, Plate XI, shows that the average specific retention increases from 6.1 per cent in coarse sand to about 21 per cent in fine sand, or an increase of nearly 15 per cent. The reason for this sharp rise can be seen when it is realized that the surface factor (page 243) varies inversely with the mean diameter of particle, and that retained water is related directly to surface factor.

Specific Yield of the Sands. From the specific yield curve, Plate XI, the maximum yield of the alluvial series represented is reached in coarse sand (maximum 10 per cent size, 1–2 millimeters), and averages about 32.5 per cent. The yield for all alluvial sand samples with maximum 10 per cent size coarser than ½ millimeter averaged by grade size is 30.9 per cent. These sands are medium to coarse sands, and are considered to be the materials commonly logged as sand and coarse sand by well drillers. The specific yield values for coarse and medium sands were seen to be so nearly the same from the

[1] Wentworth, Chester K.—A Scale of Grade and Class Terms for Clastic Sediments, Journ. of Geology, Vol. XXX, page 381, 1922.

curve, that no attempt was made to differentiate the two for storage capacity computation.

The samples the maximum 10 per cent grade sizes of which were greater than ⅛ millimeter and less than ½ millimeter were considered to be fine sands and probably represent the material logged as fine sand or quicksand by well drillers. The specific yield estimated by averaging grade sizes for fine sand is 21.3 per cent.

Since the average specific yields of coarse and medium sand were found to differ only a few per cent, no attempt was made to assign different yield values for sand in different regions, as was done for gravels. The curve shows an average of 30.9 per cent for the coarse and medium surface alluvial sands.

The sand samples used to obtain these specific yield values were taken from cuts or from borings at depths of a few feet below the surface in order to avoid the abnormally high porosities of unburied sands.

Alluvial Clays

All the unaltered deposits with maximum 10 per cent grade size less than ⅛ millimeter are considered to be in the clay group. Very fine sands, silts, and sandy clays are thus included with the clays. The sedimentary clays occur on the surface with the sands on the lower slopes and flat valley bottoms. They form a relatively small per cent of the deposits of the three upper alluvial basins, generally being absent entirely from beneath the upper slopes, and present in abundance only in comparatively small areas. In the coastal plain area they are difficult to distinguish from clays of marine origin.

The alluvial clay samples were taken from depths of a few feet below the surface and were not in any cases taken from the actual surface. Their porosities are not therefore directly comparable to those of soils.

The porosity of samples of these materials increased slightly from about 43 per cent in very fine sand and silt to nearly 45 per cent maximum in true clay. This relation is shown in the porosity curve, Plate XI. The materials sampled varied from blue to gray, fairly loose silts, through slightly sticky blue or gray sandy clays, to sticky blue clays. Because of the uncertain accuracy of the specific retention curve for finer materials, the yield values for materials finer than those classed as fine sands were determined by porosity and specific retention measurements on actual samples.

Specific Yield of the Clays. Mechanical analyses were made of only a very few of these samples, and therefore the samples were grouped according to maximum grade size by inspection of the grains under a binocular microscope. It was thought from inspection of about 30 samples in this manner that in those the maximum 10 per cent grade size of which did not exceed $\frac{1}{16}$ millimeter, the specific retention was generally about equal to the porosity. This lower limit is a rather indefinite approximation, but at any rate the materials classed as sandy clays fall on that part of the specific yield curve lying between 11 per cent yield and zero yield. It is thought that these materials are those generally called sandy clays by well drillers. More properly speaking they are very fine sands and silts. The moisture retention and porosity of several samples of sandy clay were obtained from post auger borings at the average depth of a little more than 10 feet. The average computed specific yield of these samples was approximately 10 per cent. The specific yields of nine clay samples from post auger holes were computed and found to average approximately zero.

Application of these values to equivalent buried materials of the water producing deposits is made later.

The Marine Sediments.

The marine sediments considered in the following pages are those deposits beneath the Coastal Plain which are interbedded with the alluvial deposits of the freshwater-yielding horizons. They are in most cases the age correlatives of the Palos Verdes and San Pedro formations (Qtm) shown on the geological map, Plates A, B, and C.

These marine sediments are principally shallow water deposits of gravels, sands, silts and clays. They are probably chiefly littoral and estuarine or bay deposits. They may include considerable quantities of brackish water sediments which are not truly marine.

In general the marine deposits do not differ greatly in mechanical composition nor specific yield from the corresponding types of alluvial sediments and although the two are discussed here separately they are so intimately associated with each other in the deposits of the Coastal Plain, that their separation in well logs was in many cases practically impossible. However, since it was found that the water-yielding properties of the unaltered marine sediments were similar to those of like unaltered continental sediments, they were classified in the same manner, and yield values were assigned on the basis of estimated mechanical composition without regard to their marine or continental origin. The different character of alteration of the marine and continental deposits was, however, taken into consideration in classifying the materials in well logs. This problem is discussed later.

Marine Gravels. A series of 18 gravel samples was taken for porosity determinations from marine Pleistocene terrace gravels along the Beverly-Newport uplift. The maximum 10 per cent grade size of 13 of these samples was 16–32 millimeters, and the average porosity for these 13 samples was 24.5 per cent. The computed specific yield was 20.5 per cent. These figures compared with 26.9 per cent average porosity and 21.9 per cent average yield for 36 continental gravels of corresponding size, show somewhat lower values for the marine gravels. Three samples of fine gravel had computed specific yield values of one to two per cent below those of the corresponding continental gravel averages. Two samples of 32–64 millimeters maximum 10 per cent grade size gave an average value about the same as those for the corresponding continental gravels. It does not seem safe to draw any conclusions from the scattered samples, but the average values for the 13 marine gravels in the 16–32 millimeters group are probably reliable, and indicate that the average specific yield values of these marine gravels are slightly lower than those of continental gravels of like maximum 10 per cent grade size. The mechanical analyses of these marine samples show further that they are of essentially the same size composition as the continental gravels.

Marine Sands. Twenty-three samples of marine sands were collected for porosity determination from the marine Pleistocene terrace deposits at the various locations shown on the map (Plate F), along the coast and eastward to the Beverly-Newport uplift.

The measured porosities and computed specific yields were classified according to maximum 10 per cent grade sizes. The average of 12 samples within the grade sizes from ½ millimeter to 8 millimeters representing coarse and medium sand gives the value of 35.4 per cent for porosity and 26.9 per cent for computed specific yield. Compared with values of 38.6 per cent and 30.9 per cent for porosity and specific yield values of corresponding sizes of continental sands the porosity value for marine sands is 3.2 per cent lower, and the specific yield value 4 per cent lower than the corresponding continental sand value.

Eleven samples with maximum 10 per cent grade sizes of ⅛ to ½ millimeter were taken and are considered to represent fine sands as logged by well drillers. The average porosity for these samples was 40.3 per cent, and the average computed yield for the 5 samples with maximum 10 per cent grade size of ¼–½ millimeter was 28.1 per cent. These averages compared with approximately 43 per cent and 25.4 per cent, respectively, for corresponding continental sands show lower porosities but higher specific yields for the marine samples.

The number of samples obtained for the determination of fine sand values in the cases of both continental and marine sands was too few to give accurate values or even comparable results. They do, however, show an important trend. The continental coarse and medium sands have a higher specific yield than corresponding marine sands, but the yield peak for continental sands is apparently reached in coarser materials, and as a result, marine fine sands appear to have a higher specific yield than continental fine sands.

Marine Clays. The marine clay group includes very fine sands, silts and clays. Many samples from wells showed these materials to be so similar in appearance and composition to the continental clays that they were distinguishable only in the cases where they contained fossil material. Since the specific yield of the true clays is zero and that of the silts and sandy clays only a few per cent, small differences which might occur between marine and continental specific yield values were considered to be negligible and the few surface samples of marine clay group collected were included with the continental unweathered clay group.

PROPERTIES OF THE WATER-PRODUCING DEPOSITS

The water-yielding properties of the unaltered surface sediments, in the condition that they were originally deposited, have been considered in the foregoing pages. However, the sediments do not long remain in an unaltered condition, and in order to learn the true nature of the materials now present in the ground water basins, it is necessary also to consider the changes that have taken place in the sediments after their deposition. This second phase has, in the present study, been found to be of no less importance than the initial condition of the deposits in determining their present character. Alteration of one type or another has affected practically all of the water-producing deposits, and therefore the various types and extent of alteration are discussed in some detail in the following pages.

Weathering.

Alluvial deposits of the South Coastal Basin have undergone profound changes through the agency of weathering since their deposition. Only a small part of their surface is covered by unaltered debris from the mountain canyons. Soils formed by weathering of the original deposits cover the greater part of the surface and the extent to which this weathering has altered the deposits varies with the locality. Soil maps[1] of the U. S. Department of Agriculture show only a very small per cent of the surfaces of the piedmont basins (San Fernando, San Gabriel and Upper Santa Ana) and the coastal plain to be covered by unaltered debris. These areas are the present washes and represent the most recent phase of deposition. They are shown on the soil maps as ''Riverwash.''

Outside the actual recent washes, but associated with them, the soil maps cited above show a series of recent alluvial soils which include the following soil groups: Tujunga, Hanford, Chino, Yolo, and Dublin. These soils in general cover the areas of active deposition. They are only slightly modified gravels, sands, and silts. Locally, the finer facies have been somewhat modified by weathering, and a large part of the clay present in them is probably due to decomposition of the original sediments. These materials are shown as Recent alluvium on the geologic map (Plates A, B, and C). The undissected Recent alluvium covers the low flat central parts of the piedmont valleys with tongues running up onto the cones toward the canyon mouths. Slightly dissected surfaces are generally only moderately altered and the materials on them have been mapped as Recent alluvium.

Extensive areas in the piedmont basins and on the coastal plain, that have long been undergoing dissection, are so completely modified by weathering that their surfaces are covered by deep reddish or yellowish-brown gritty clayey soils, in which all traces of the original bedded structure have been lost. These soils are mapped on the U. S. Department of Agriculture soil maps as old alluvial soils under the following groups: Placentia, Ramona, Pleasanton, Madera, etc. They are residual soils, developed by oxidation above the water table of alluvial or marine deposits in place. A description of Ramona loam,[2] the most common type, shows their general nature.

"The Ramona loam, which greatly predominates, is a brown to slightly reddish-brown heavy sandy loam or light loam to a heavy loam, with a variation of grayish-brown color. The soil ranges in depth from 10 to 24 inches, is in many places micaceous, is sticky when wet and rather compact, and hardens upon drying if uncultivated. In poorly drained depressions the soil is sometimes puddled. The subsoil consists of brown to reddish-brown clay loam to clay, compact and dense in structure extending to a depth of 4 to 6 feet. It is sufficiently hard to prevent the percolation of water and to obstruct more or less the proper development of the root systems of deep-rooted plants and trees. The subsoil material contains in many places finely divided mica and varying quantities of gritty particles. When wet it is sticky and where exposed it becomes flinty and hard and cracks upon drying. The substratum is in most cases, but not everywhere, lighter in texture than the subsoil. It may consist of a loam or light clay loam closely resembling the surface soil, or of stratified beds of gravel, silt and sand."

[1] Dunn, J. E., and others, Reconnaissance Soil Survey of the Central Southern Area, California. U. S. Dept. of Agriculture, Advance Sheets—Field Operations of the Bureau of Soils, 1917.

[2] *Op. cit.*, pp. 62–63.

Beneath the subsoil referred to above, there is a weathered zone extending downward sometimes for many feet to the water table. A typical section beneath Ramona loam exposed in a 100-foot bank on the east side of San Dimas Wash, a short distance below the canyon mouth, shows weathered red and yellow gravels with occasional buried red soil streaks 1 to 2 feet thick. The gravels are decomposed to such an extent that most of the individual pebbles can be broken in the hand. It is interesting to note that comparatively fresh gravels alternate with badly decomposed gravels and soils. Evidently the dominant effects of weathering upon the badly decomposed gravels and soils were produced while these materials were at the surface. However, the fact that all the gravels are somewhat decomposed seems to indicate that weathering continues to be effective below the soil zone down to the water table.

Red or reddish-brown, iron-stained, clayey, gritty soils characteristically form on the steep upper slopes. These soils give way to yellowish and yellowish-brown sandy clay soils on the lower slopes, and in the flat poorly-drained areas, where the water table is usually high, the yellowish-brown varieties of weathered soils give way to dark brown, black, or gray adobe soils. Weathering beneath these soils is generally limited to a few feet in depth.

Less weathered soil phases often contain part of the original structure. In these the resistant quartzose pebbles and cobbles are embedded in clayey, gritty material, and thus form a gravelly clay.

The soil maps referred to above show large areas of weathered soils, and approximately these same areas are mapped as Quaternary Older alluvium and marine terrace deposits on the geological map, Plates A, B, and C. On the coastal plain there is a belt of them distributed from the Santa Monica Mountains near Santa Monica, southeasterly to the San Joaquin Hills east of Newport, along the line of the Inglewood fault zone. These represent an area of recent uplift. Weathering has here affected sediments chiefly of marine origin.

Weathered red-brown soils are prominent along the south base of the Repetto and Puente Hills, eastward from Los Angeles to the mouth of Santa Ana Canyon. They occur also along the Santa Fe Springs-Coyote uplift.

In San Fernando Valley, deeply weathered soils cover a large part of the northern end of the valley in the vicinity of San Fernando, and are distributed locally around the margins wherever dissected cones occur.

In San Gabriel Valley almost the entire portion north of the Raymond Uplift (Plate A) in the vicinity of Pasadena is covered by a thick mantle of weathered reddish-brown clayey soil. The western part of the valley south of this uplift is also covered by weathered red-brown soil. In this area the reason for extensive weathering appears to be that the Arroyo Seco has abandoned its alluvial cone to flow southwesterly through low hills into Los Angeles River, leaving the cone surface to become weathered, and then dissected by its own run-off.

Eastward along the mountain front many small dissected cones have weathered red-brown clay soil surfaces. At the east end of the valley, San Dimas Wash is incised to a depth of 50 to 125 feet below its cone surface. The old surface is covered by a thick mantle of Ramona loam.

In the upper Santa Ana basin, Red Hill near Upland, and Indian Hill near Claremont, are conspicuous isolated areas with deeply weathered soil surfaces. In both cases local uplift has caused weathering and dissection of the uplifted portions, of which these hills are remnants.

In the southeast part of the Upper Santa Ana basin there are two large areas covered by weathered surfaces. The high dissected alluvial cone surfaces in the Yucaipa-Beaumont area, southeast of Redlands, and the eroded folded alluvium in this region are covered by deep reddish soils. The Riverside-Highgrove Terrace, 50 to 75 feet above the present flood plain of the Santa Ana River, is covered by old weathered soil (Older alluvium).

North of Corona there is an area of weathered alluvium. Temescal and Santa Ana River are here incised about 100 feet into old alluvial cones from the south and west. The hummocky surface of the dissected cones is a gravelly clay soil of the Antioch type. It disappears to the north beneath the recent alluvium of San Antonio Creek.

Many other small areas with deeply weathered soil surfaces occur within the alluvial basins, but their absence is conspicuous in the low central parts of the basins, where active deposition is in progress.

The wide distribution of weathered soils over the surfaces of the alluvial cones suggests that similar conditions may have existed throughout the accumulation of the alluvium and therefore buried weathered materials may occur beneath the surface and have an important effect upon the water-yielding capacity of the formation.

The Occurrence of Weathered Materials Beneath the Surface. Although it is true of the alluvial cones in this region, as it is of those in other localities, that the coarsest material is deposited at the canyon mouths, with the finer materials distributed farther out upon the cones, well logs show very clearly that the quantity of clay present in vertical section does not increase as a function of distance from cone apex. The reason for this is that the clays and clayey gravels were in large part formed by decomposition of alluvium above the water table and were not deposited as original clays. Compact red, yellow and brown residual clay, conglomerate partly altered to clay, and occasional thin beds of calcite-cemented conglomerate, interbedded with water yielding sand and gravel, comprise the alluvial deposits beneath the upper slopes of the cones.

It is interesting to contrast the lithologic distribution of the alluvial deposits found in the South Coastal Basin with the distribution usually assigned to an alluvial cone. Clays are not confined to the distal parts of the cones, but are most abundant near the mountains, and are almost the only deposits found between the major canyon mouths in some areas along the mountain fronts. This apparently anomalous situation exists because the formation of clays upon the piedmont slopes has been controlled by surface decomposition of the gravel, and not by deposition.

Clay, silt and fine sand have been deposited on the lower portions of the cones, but the abundant clays and clayey deposits of the piedmont are nearly all residual deposits.

No attempt is made here to describe in detail the distribution of clayey materials throughout the South Coastal Basin. An example from the San Gabriel Valley which is thought to be typical is cited however.

The Arroyo Seco, Eaton and Santa Anita cones, together with adjacent smaller cones, comprise the northwest part of the San Gabriel Basin. Table 4 gives the relative amounts of gravel, sand and clay recorded from well logs in that part of these cones north of the Raymond uplift, in that part between the Raymond uplift and the Central San Gabriel Valley, and in the Central San Gabriel Valley itself.

PLATE XII

Residual (reddish-brown) clay overlain by slightly decomposed gravels in tilted Older alluvium, northwest of Montebello.

TABLE 4

PERCENTAGES OF GRAVEL, SAND AND CLAY IN DIFFERENT PARTS OF THE SAN GABRIEL VALLEY

Locality	Gravel	Sand	Clay
Pasadena area	48.5	2.9	48.6
San Gabriel-Arcadia area	43.5	10.9	45.7
Central San Gabriel Valley	56.5	23.0	15.4

The steeply sloping cones in the Pasadena Area contain the highest percentage of clay (48.5 per cent). The lower parts of these cones in the San Gabriel-Arcadia area have a lower slope and slightly smaller percentage of clay, but a higher percentage of sand. The central San Gabriel Valley area (San Gabriel River cone) has a very low percentage of clay (15.4 per cent) but a relatively high ratio of sand to gravel. This area has the lowest slope of any part of the basin. The ratio of sand to gravel increases as the distance from the mountains increases, or with decreasing slope. The clay percentage, on the other hand, decreases toward the low central part of the valley. In the areas that are too steep for the accumulation of sand deposits, it is obvious that the clay has resulted from the processes of weathering and not from deposition. Evidently the lower slope in the San Gabriel-Arcadia Area is still too great to permit the deposition of much fine material, since there is only 11.4 per cent of sand present.

From this analysis it would appear that clays have been deposited only in the lowest parts of the piedmont basins, and there only in minor amounts. The abundant clay deposits beneath the upper slopes have been formed by the weathering of gravels.

Data obtained in the field during drilling of water wells in the South Coastal Basin show that every gradation from clean unweathered gravels, through partly weathered materials, to red, yellow, and brown residual clays in which the original sedimentary structure has entirely disappeared are the characteristic materials found beneath the upper and intermediate slopes. Sand is conspicuously rare. The data obtained show further that beneath the lower slopes of the upper basins and again well out on the coastal plain, the weathered materials give way to gray and blue sedimentary silts and clays, interbedded with considerable sand and gravel. The gravel is generally loose, unweathered and a good producer of water.

An inspection of the well logs leads to the same conclusion. Beneath the upper slopes yellow, red and brown clays are reported, together with much tight gravel and gravelly clay. Each red or brown clay stratum marks a former erosion surface, and its thickness gives some measure of the relative length of time that elapsed between deposition of its gravels and those overlying it. Downstream beneath the flatter slopes, logs show considerable amounts of sand and loose gravel, with gray and blue silts and sedimentary clays predominating over the weathered yellow or red residual varieties.

Origin of the Weathered Deposits. A consideration of the processes at work upon the present alluvial surfaces suggests the mode by which the complex series of alternating residual clays and unweathered deposits has accumulated on the piedmont slopes. Portions of the alluvial cones that are undergoing active deposition are being covered by unweathered gray deposits. Simultaneously, on the portions of these same cones remote from active deposition the gravels at the surface are breaking down to form red-brown soil clays. During the long and complex history of alluvial deposition in this area, accumulation of detritrus has not been continuous over the whole cone. consequently red soil clays have developed on differenet parts of the cones at different periods, later to be buried by fresh deposits, and thus alternate with unweathered or partly weathered deposits in vertical section.

Briefly stated, the principal conditions necessary to the formation of residual red-brown clay soils are: (1) time to permit complete action of weathering, that is, protection from destruction by active streams or other agencies; (2) well-defined annual wet and dry seasons; (3) a water table sufficiently low so that the capillary fringe does not reach up into the root zone; and (4)iron bearing constituent minerals, Such conditions are normal near the mountains in areas between the mouths of the major canyons. The alluvial cone heads are periodically trenched by their parent streams. These trenches are deepest at the cone apices and die out downstream. Consequently the dissected alluvial surfaces in these regions are remote from the activities of the major streams and thus are subject to long undisturbed periods of weathering. Just such an area exists around La Verne, which lies between the cones of San Dimas and San Antonio Creeks. North of La Verne, many wells penetrate reddish-brown gritty residual clays almost continuously from the surface to bedrock, a depth of several hundred feet, and occasional gravels are themselves characteristically clayey. The extensive development of red clay soils along the mountain front is in large part the result of this normal dissection.

Local deformation by faulting or folding of alluvial surfaces brings portions of them above the general level and permits them to be dissected. Red clay soils tend to develop on these surfaces. Red Hill, and Indian Hill in the upper Santa Ana Basin, and the row of hills along the Beverly-Newport fault zone owe their origin to such a cause.

In nearly any well drilled on the upper part of a cone near the foothills, several weathered soil clay surfaces can be recognized. Each of these buried erosion surfaces represents a time lapse in deposition comparable to that between deposition of weathered surfaces such as the one upon which Pasadena is built, and deposition of the gravels in the recent washes. Thus this break in the record of alluvial deposition so apparent at the surface between the undissected gravels and the dissected red altered gravels has been repeated many times, and loses its importance in the perspective of a vertical section. This difference between surfaces appears to be simply the surface expression of a complex and variable system of local unconformities that have developed contemporaneously with the alluvial deposits.

Although alternations between more or less unweathered gravels and red clays occur in well sections throughout the area, red clays generally predominate in places which appear favorable for their development today, and the less weathered phases predominate where stream action might be expected to be most continuous. Mendenhall[1] divided the Quaternary alluvial surfaces of the "foothill" belt into two parts. The fresh gray alluvium he assigned to "later alluvium" and the weathered red alluvium he assigned to "earlier alluvium." These two divisions for the surface deposits are shown on the geologic map (Plates A, B, and C) as "Recent alluvium" and "Older alluvium" respectively. The older surfaces were considered to represent a period of general erosion after deposition of the "earlier alluvium," during which the valleys and hills were eroded out, and an irregular surface of deeply weathered red clay was formed. The "later alluvium," resulting from renewed uplift of the mountains, was considered to have filled the valleys, and buried most of the hills of "earlier alluvium."

Evidence for this theory lay in the presence of such remnants as Red Hill and Indian Hill coincident with groundwater barriers ("dikes").

[1] Mendenhall, W. C. U. S. Geological Survey Water Supply Paper 219, pp. 11–12, 1905.

Extensive well development since the pioneer work of Mendenhall, together with further geologic study, has brought forth several lines of evidence which minimize the general significance of the break between "earlier" alluvial surfaces, and "later" alluvial surfaces, and show that these breaks do not usually mean two distinct periods of alluviation separated by a general period of erosion. Instead, it appears that there has been more or less continuous deposition in the alluvial basins accompanied by local areas temporarily dissected from various causes, upon which weathered red or brown surfaces formed, later to be buried by the accumulating deposits.

The evidence may be briefly summarized from the foregoing pages as follows (1) residual red clays alternate with comparatively unaltered gravels from the surface to bedrock; (2) decomposed materials are encountered beneath recent gravels over large areas within 50 to 75 feet of the surface, showing that fresh gravels at the surface do not mean that there is a deep fill of recent unaltered material; (3) even in areas in which coarse loose gravels predominate to great depths, occasional strata of red clays and clay-cemented gravels occur; (4) mid-cone remnants of "earlier alluvium," such as Red Hill, are in most cases traceable to local folding or faulting of the alluvium.

The alluvial cone may be considered to have two zones of deposition: (1) the upper part (near the cone apex) beneath which weathered materials predominate over unweathered materials, or the zone of intermittent deposition; (2) the lower part (toward the distal part of the cone), beneath which the gravels, sands and clays are unweathered or only slightly weathered, the zone of continued deposition. The agency of weathering operates continuously over the surface of an alluvial cone, and downward with diminishing effect to the water table. Therefore, the degree to which any part of an alluvial deposit has been altered by weathering depends upon the ratio between rate of weathering and rate of deposition for that part. Assuming that weathering is a relatively constant factor, it follows that except in the immediate vicinity of canyon mouths (where the weathered products may be removed by erosion), the central parts of alluvial basins where the deposits are thickest will generally contain a lower percentage of weathered material than the marginal regions where the deposits are relatively thin. This, in short, is the explanation of the fact that near the upper basin margins weathered deposits predominate, and in the central parts they are only a minor constituent.

The General Significance of Weathering in Continental Deposits. It would appear from the foregoing analysis that alteration of the alluvial deposits by weathering has proceeded throughout their accumulation in rather definite areas which are dependent in large part upon the physical features of the cones themselves, such as size and arrangement.

It appears from this that deposits decomposed by weathering are characteristic of certain parts of alluvial deposits and are not necessarily due to special conditions arising from such causes as local deformation or changes of climate. Well logs from Santa Clara Valley near San Jose, Salinas Valley and Santa Clara River Valley in Ventura County, all outside the South Coastal Basin, were studied. In each case the logs reported yellow, red, or brown clays, and gravelly clays near the foothills, grading into unweathered blue or gray clays and loose sands and gravels toward the central parts of the basins. Similar conditions were reported by Kirk Bryan[1] along the margins of the Sacramento Valley. These conditions probably occur in other California basins. Evidence that they are not the result of climatic or other conditions peculiar to the Quaternary geological period is found in the South Coastal Basin. Folded Pliocene or early Pleistocene alluvial deposits (Saugus formation) northwest of San Fernando contain much weathered material in places. The weathered beds conform to the stratification and not to the present surface. Folded Pliocene (?) sediments southeast of Redlands near Yucaipa show similar characteristics. The closely folded Miocene alluvial conglomerates along the base of the San Gabriels northeast of Monrovia contain deeply weathered red gritty clay beds that conform to the strata. Evidently, in the cases noted, alteration by weathering occurred during accumulation of the deposits and is readily distinguishable from the recent weathering that conforms to the present surface. Other similar examples occur in the folded continental deposits of the South Coastal Basin.

Although the rate and nature of weathering varies greatly in different localities it operates on all land surfaces, and with the evidence at hand to show the geographic and geologic distribution of its effects on alluvial deposits it seems reasonable that weathered materials should be anticipated in all alluvial deposits. In many cases weathering has undoubtedly been the most effective single agent in reducing the permeability and specific yield of a water-bearing deposit.

The Effect of Weathering Upon the Specific Yield. Since weathering has been an important agent of alteration in South Coastal Basin water-producing sediments, the effect of this alteration upon specific yield was analyzed.

The weathering of solid rock such as granite produces a rather porous soil mantle, grading downward into solid rock. In areas of low relief this "residuum" may accumulate to considerable depth and form an important local source of groundwater which, though a poor producer of water, is better than the solid rock from which it is derived.

The weathering of alluvial gravels, however, does not cause the same relative effect. As the gravels break down into their mineral constituents, the fine materials produced fill the relatively large voids of the original gravel, forming a clayey matrix. Finally, as the gravel is completely broken down, a clayey aggregate containing gritty fragments of resistant quartzose material remains. This end product has a porosity probably not much different than that of the original gravel, but the number of particles is so greatly increased, with consequent decrease of size of pores and increase in surface that the specific yield is practically zero.

Thus it can be seen that weathered sands and gravels form a continuous series with the specific yield of the original unaltered material at one end, and, at the other end, where the material is residual clay, zero specific yield. The classification of these materials into convenient groups must, therefore, be arbitrary. This classifica-

[1] Bryan, Kirk, Geology and Ground-Water Resources of the Sacramento Valley, California. U. S. Geological Survey Water-Supply Paper 495, p. 74, 1923.

tion and the assignment of yield values to the groups is described later.

Compaction.

Compaction of a sediment is any movement of the solid material after original deposition, which tends to fill the interstices and thus to reduce the whole volume occupied by the sediment. The direct result of compaction is reduction of pore space. The process seems to take place principally in three ways: (1) by settling; that is, by rearrangement of the particles so that they are more closely packed; (2) by downward movement of fine particles after deposition; and (3) by deformation and breaking of the particles themselves.

Settling. This affects all types of sediments but its principal effect seems to take place within a few feet of the surface. L. F. Athy [1] discusses the settling of sand and gives the results of laboratory tests. He says, "A column of St. Peter sand deposited under water settles about 11 per cent with continuous jarring under atmospheric pressure. If placed under 4000 pounds pressure, the compaction is about 2 per cent more, or 13 per cent in all." Similar results were obtained in the present investigation.

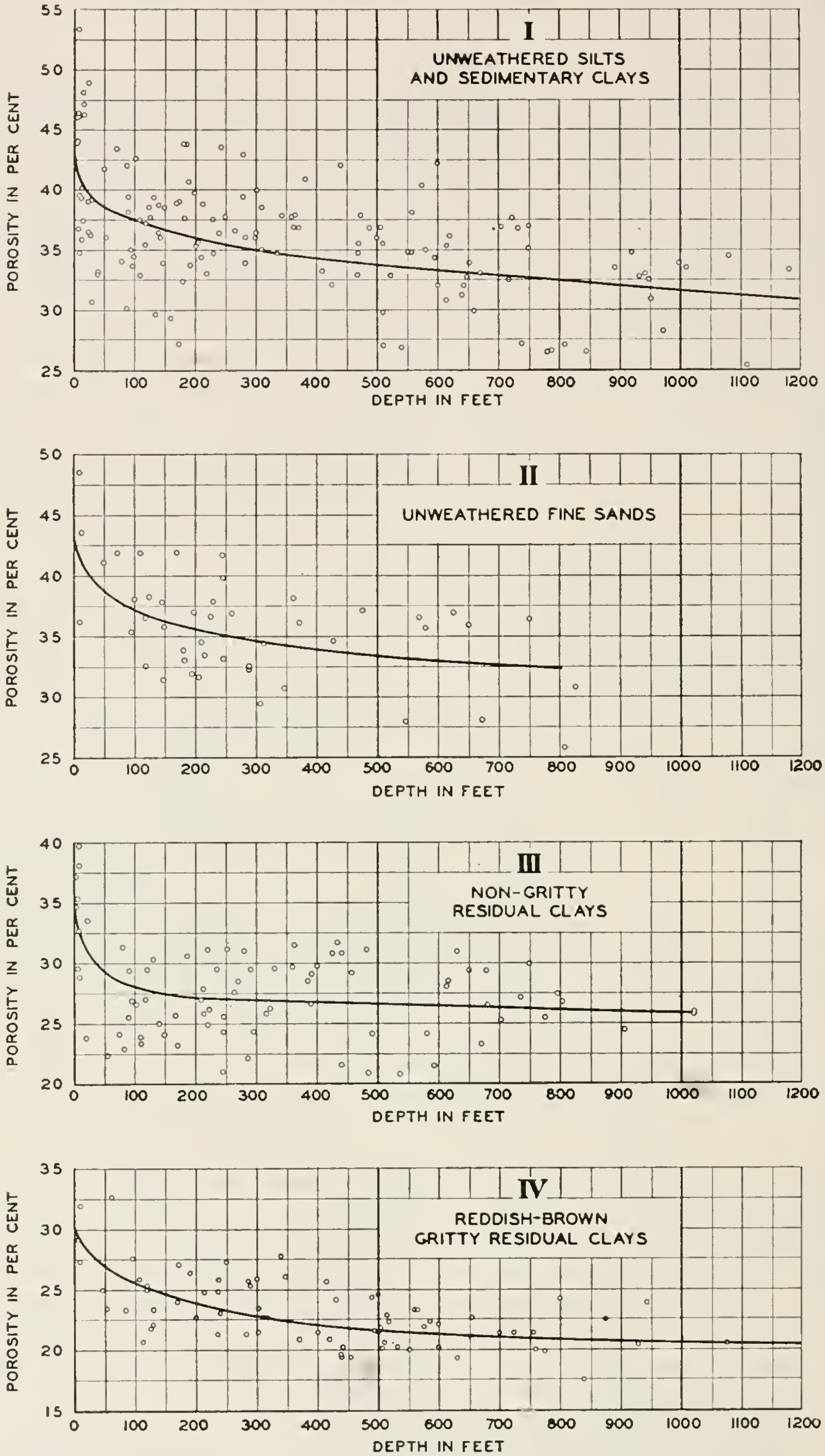
In order to show the effect of compaction upon the porosity of different kinds of materials, the results of porosity tests on more than 300 samples are shown graphically in Plate XIII, porosity being plotted against depth. Curve I represents unweathered silt, sandy clay and clay; Curve II represents unweathered fine sand; Curve III, residual (weathered) nongritty red-brown clay; and IV, residual (weathered) red-brown gritty clay. The outstanding characteristic of these curves is the sharp drop in porosity shown from the surface to depths of 50 to 150 feet, with more gentle slopes of decreasing porosity with greater depth. The very sharp decline of per cent porosity for a short distance below the surface (especially in the cases of Groups I and II) is probably due principally to settling effects. Fine sand (Group II) shows a loss of porosity from 43 per cent at the surface to about 38 per cent at the depth of 50 feet. The surface values were derived from samples taken at less than 10 feet depth, but not actually on the surface. Had samples been taken on the actual surface the values would no doubt have been several per cent higher, and the effects of settling would have been even more pronounced.

Slight settling is known to occur at depth, however. The Long Beach earthquake of March 10, 1933, caused a temporary rise in water levels of several feet in that part of the Coastal Plain in which the groundwater is under pressure. Outside the pressure area any rise in water levels was too slight to be recorded. Evidently the shake produced a very slight settling effect which registered an increased pressure upon the confined water, but failed to reduce the porosity a measurable amount in the area where reduction of pore space would be measurable directly by rise of water levels.

Downward Movement of Particles. During the formation of soils fine materials found at the surface work downward past coarser materials and fill the interstices of the subsoil. In this manner layers of

[1] Athy, L. F., Density, Porosity, and Compaction of Sedimentary Rocks. Bull. Am. Assoc. Pet. Geologists, Vol. 14, pp. 8–9, 1930.

PLATE XIII



RELATION OF POROSITY TO DEPTH
IN
CERTAIN TYPES OF SEDIMENTARY MATERIALS
IN THE
SOUTH COASTAL BASIN

compact clayey material with reduced porosities are found beneath the soil surface. Water is probably the chief agent of transportation although some material probably works downward simply by gravity. Downward migration of fine particles is probably confined to the zone of weathering and occurs almost entirely in the zone of soil formation, for it is in this zone only that decomposition continually supplies an abundance of fine materials. Compact beds of residual clays, often gritty, result.

Deformation of the Particles. Deformation of the original particles (with consequent rearrangement) is the only form of compaction that appears to continue to be effective with deep burial of a deposit. L. F. Athy[1] has determined the loss of porosity due to compaction in fine sediments for depths greater than 1500 feet. His curve, representing the porosities of 200 samples, shows an average porosity of 25 per cent at 1500 feet with a gradual decrease to about 2.5 per cent at 7000 feet. These sediments were assumed to have had surface porosities of about 48 per cent. This curve projected to the surface indicates nearly 50 per cent loss of porosity between the surface and the depth of 1500 feet, with a comparable loss between 1500 feet and 7000 feet. For the purposes of the present investigation only values from depths of less than 1000 feet are significant.

The principal factors that determine the amount of compaction by deformation are: (1) shape of the original particles, angular particles being more readily deformed or broken than round particles; (2) crushing strength; and (3) the load or other compressive forces acting upon the deposit. The element of time is important also.

In the present study it has been important to determine the types of material affected and the relative amount each type has been affected. Within the depths considered in this investigation there were probably only two types of material appreciably compacted below very shallow depths. One of these types comprises the fine sediments, fine sands, silts, sandy clays, and clays. The second type affected was the group of weathered materials. Even coarse gravels, if sufficiently weathered, can not withstand the load of overlying sediments and are deformed under it.

Compaction of Unweathered Sediments. The curves, Plate XIII, show the effects of compaction by deformation upon the types noted. The more gentle slopes for depths greater than 50 to 150 feet probably reflect the effects of compaction by actual deformation of the particles.

The fine sand (Curve II) corresponds to fine sand of Plate XI, which gives an average porosity for the practically unaltered surface deposits of 43 per cent. The well samples show a drop in porosity to an average of a little less than 38 per cent at a depth of 50 feet, a two per cent loss in the next 100 feet, and a very small average change below 200 feet. The silt, sandy clay and clay curve showing a surface porosity of 44 per cent, drops to an average of 39 per cent, at 50 feet depth, and to about 36.5 per cent at the depth of 1000 feet.

Compaction of Weathered Materials. Curves III and IV, Plate XIII, show the effect of compaction on the porosity of weathered materials. The materials of Curve III (nongritty residual clay) appear

[1] *Op. cit.*, pp. 13–15.

from their texture to have been derived by decomposition from sands, and those of Curve IV (gritty residual clay) from gravels.

These curves show a less pronounced effect from settling in the upper 50 feet than those of unweathered materials, but in the case of Curve IV, the porosity decreases continuously from about 30 per cent at the surface to 21 per cent at the depth of 1100 feet. The decrease is only a little more rapid near the surface. Curve III is somewhat different. The porosity is about 33.5 per cent at the surface, 30 per cent at the depth of 100 feet, below which the curve gradually flattens, losing only 2.5 per cent porosity from the depth of 100 feet to 1000 feet. Possibly the less uniform texture of the gritty clays (Curve IV) accounts for their steeper porosity decline curve.

The samples from which surface porosities were estimated for the residual clays were from depths of a few feet below the surface, and were, therefore, probably somewhat compacted by accumulation of fines due to downward movement of particles from the top soil. It may be for this reason that settling had less effect than in the cases of unweathered materials.

The Effect of Compaction on Specific Yield. Compaction reduces the porosity of a sediment and therefore reduces the specific yield directly by the amount of reduction in pore space. It probably has a secondary effect upon specific yield in that it reduces the size of openings and thus tends to increase the specific retention. This effect is probably important in finer materials.

From the foregoing discussion it can be seen that settling is the dominant compacting influence on sediments when depths of a few hundred feet are considered. Since the effect of settling is felt by both weathered and unweathered materials its effect upon specific yield can not be disregarded when applying yield values determined from surface samples to the materials which occur beneath the surface. Consequently the effect of settling on different types of sediments has been estimated and yield values lowered accordingly. This estimated effect of settling is described later.

Cementation.

Cementing materials that fill the interstices of sediments have so completely cemented some of the older sedimentary formations that beds which once yielded water freely are now impermeable.

The effect upon the Quaternary water-bearing series in this area has been much less extensive. Two agents of chemical cementation were recognized in the deposits: (1) the formation of iron oxides, and (2) the formation of lime carbonates.

Iron oxides have formed coincident with weathering and have in many cases firmly cemented subsoils, producing hardpan. This type of cementation is characteristic of the weathered deposits and its effect was considered to be part of weathering.

Lime carbonates in the form of caliche have accumulated in the soil zone in areas where the water table was high. Such deposits form a very small per cent of the sediments in the South Coastal Basin. Below the water table lime carbonates have cemented streaks of gravel and sand throughout the water-bearing series. These streaks, in the piedmont alluvial basins, are local, thin and sharply defined.

They seldom exceed one or two feet in thickness and comprise only a few per cent of the thickness of the deposits. The porosities of cemented sands and fine gravels from the piedmont basins were found to vary sharply, porosities between 15 and 30 per cent being most common.

The water-bearing series beneath the Coastal Plain contains somewhat more lime cement than that of the upper basins. Cemented samples generally showed porosities between 5 per cent and 20 per cent with occasional values both higher and lower.

The well logs show that chemical cementation has been a minor factor in consolidating the water-bearing series. However, the effect of cementation was taken into account in determining specific yield values for the water-producing formations. (See Table 5.)

Specific Yield of the Freshwater-Producing Sediments of the South Coastal Basin.

Specific yield values have been estimated for the different types of material that fill the freshwater-producing basins, by adaptation of the results of experiments with surface samples to similar materials encountered in wells.

In order to assign specific yield values to the various types of sediments in the ground water basins the unaltered sediments, with their specific yield values shown on Plate XI, were classified into gravel, sand, and clay groups with subdivisions under each. Then the corresponding types of materials encountered in wells were classified under each of these groups, and divided into four stages to represent various degrees of alteration, from fresh material to residual clay. The specific yield of each type for each stage of alteration recognized was estimated from the yield of its unaltered derivative. The classification with the yield values is shown in Table 5.

TABLE 5

ESTIMATED SPECIFIC YIELD VALUES FOR SEDIMENTS OF THE SOUTH COASTAL BASIN

	Per cent yield, gravel				Per cent yield, sand		Per cent yield, clay	
	256+ mm., boulders	64–256 mm., coarse	16–64 mm., medium	8–16 mm., fine	½–8 mm., coarse medium	⅛–½ mm., fine	Sandy	Clay
Unweathered—								
Surface alluvial	(1) 13.6	14.2	20.5	26.5	30.9	21.2	10	1
Sub-surface alluvial	(2) 13	14	20	25	28	16	5	1
Weathered subsurface—								
Tight*	(3) 9	9	13	17	16			
Clayey**	(4) 4	5	7	8	5			
Residual clay***	(5) 1	1	1	1	1		1	

*Lime cemented gravels are included in tight gravels.
**Lime cemented sands are included in clayey sand.
***The yield of one makes allowance for small sandy or gravelly streaks.

The Unweathered Deposits. Line 1, Table 5, gives yield values averaged from the specific yield of the unaltered gravel curve, Plate XI. These values having been derived from practically unaltered surface samples could not be directly applied to the subsurface materials. Line 2 gives the specific yields estimated for subsurface unweathered materials. These values were modified from those of Line 1, because of settling.

The gravel values were reduced only slightly, as it seemed probable that the effects of settling, greatest in sand and clay, would become less with coarser materials and probably practically die out with very coarse poorly sorted gravel and boulders. Thus the specific yield of coarse to medium gravels was reduced an average of five-tenths of one per cent (to the nearest whole number), fine gravel 1.5 per cent, coarse and medium sand 3 per cent, fine sand and sandy clay each about 5 per cent. From Curves I and II, of Plate XIII, the loss of porosity from the surface to the depth of 50 feet appeared to be about 5 per cent porosity. The depth of 50 feet, being below the steepest part of the curves, was thought to represent a fair average for the amount of compaction, and to take into account practically all of the near surface consolidation due to settling. It seems that lowering the specific yield of these materials (fine sand and sandy clay) 5 per cent is conservative, since the specific yield may drop even more than the porosity. The values for coarser sands and gravels, though not measured, were reduced correspondingly less, estimates in all cases being made to the nearest whole number.

These subsurface values (Line 2, Table 5), estimated from the surface sample averages, represent the unweathered materials of the water-producing section and include such types logged by well drillers, as loose water gravel and loose or running sand, which are the best water-yielding sediments of the formation.

The map (Plate F), showing lines of equal specific yield of unweathered gravels for the South Coastal Basin, was made up by application of the specific yield values from Line 2, Table 5, to both the maximum 10 per cent size distribution on the cones, and to the estimated maximum 10 per cent grade size of gravels in samples obtained during drilling of water wells.

The well samples showed significant size differences from surface gravels only at considerable distances from the mountains and in the regions where the gravels were interbedded with sands and fine gravels. In these areas the materials on the surface do not represent the true average coarseness because the coarser gravels are usually covered by finer material deposited during the later stages of flood. The well samples were, in such cases, relied upon for size estimates. Values for practically the entire coastal plain were determined in this manner. Well samples were not available for large parts of the upper slopes of the basins and in these areas it was necessary to apply the surface size distribution to the buried materials. The two were thought to be comparable because no significant average size differences were noted between surface and depth conditions where well samples were obtained from the regions of coarse gravel.

Although well samples showed some differences in gravel sizes at different depths, the data were not complete enough to make possible the assignment of correspondingly different values. This inaccuracy is thought to be unimportant since doubling the maximum 10 per cent size changes the specific yield only a few per cent, and well samples seldom indicate consistent size changes of one grade size with change of depth.

In order to compare the marine gravel samples taken at the surface with those of the water-producing deposits, estimates of the average maximum 10 per cent sizes of 18 gravel samples from wells penetrating marine sediments were made. The individual estimates ranged from more than 64 millimeters down to about 8 millimeters, but the estimated average was 16–32 millimeters. Most of the surface samples were approximately the size of this average, and since the surface gravels sampled appeared to have been laid down under conditions similar to those under which the water-bearing marine gravels were deposited, the two were thought to be comparable. Therefore since the surface sample values checked closely with the continental gravel averages no attempt was made to separate unaltered marine from continental gravels in well logs.

The Weathered Deposits. Since all variations in specific yield from those of the unaltered deposits, to zero for residual clay, occur in weathered deposits, it was found necessary to make an arbitrary classification for the purpose of assigning specific yield values.

The specific yield of weathered gravels and sands depends on: (1) the specific yield of the unweathered deposit, and (2) the extent to which alteration has progressed. Slightly weathered gravels and sands that have retained their original structure are generally classified as tight gravels or tight sands by well drillers. Gravels and sands that have lost a large part of their original structure but retain resistant pebbles or cobbles embedded in a clayey sandy matrix are generally classed as gravelly clays and sandy clays. Gravels and sands that have been altered to red, brown, or gray clayey soils with gritty angular residual fragments embedded, are usually called clay by well drillers. These classifications were adopted and specific yield values assigned accordingly.

The specific yields of the weathered materials could not be successfully classified from measurements on actual samples because of the nature of variation. Therefore specific yields were assigned by making an arbitrary division according to the degree of alteration. Tight gravel was given a yield value of two-thirds that of unweathered subsurface gravel, and gravelly clay, one-third the specific yield of unweathered subsurface gravel. Probably the typical residual clay has a yield of zero, but since it is highly variable in composition it undoubtedly contains streaks that yield small quantities of water. It was, therefore, assigned a specific yield of one to indicate a probable slight yield throughout the well section.

The estimation of yield values for weathered sand was less simple. It was found that the decomposition of sand reduced the specific yield sharply, so that materials logged as tight sand had a specific yield value less than two-thirds that of good sand. Sandy clay formed by decomposition, being similar in mechanical composition to unweathered sandy clay, probably has an average specific yield similar to that of unweathered sandy clay.

Since unaltered sands were classified according to coarseness, as sand, fine sand and sandy clay, the two finer divisions were so similar to tight sand and sandy clay (weathered) that it was impossible to separate them in well logs. Therefore the value of 16 per cent assigned to fine sand was used also for tight sand, and all sandy clays were considered to yield 5 per cent.

Computation of Specific Yield and Storage Capacity.

Classification and Use of Well Logs. The distribution of different types of materials in the alluvial basins is erratic, and individual strata are so discontinuous that it is not in most cases possible to correlate materials from one well to another. Consequently the section reported in a single well log does not give a true picture of the formation beyond the immediate vicinity of the well. In order, therefore, to make use of the well logs to determine the nature of the deposits, the logs were combined into groups with two to twelve logs in each group and the materials were averaged together in vertical intervals by depth. In this manner composite logs were obtained which it was thought would approximate the average conditions about the centers of the respective well groups.

The well logs were classified as differentiated or undifferentiated logs on the basis of the well driller's designations. The logs that recorded the materials penetrated, under only the three major divisions, gravel, sand, and clay, were classed as undifferentiated. Poorly or partly differentiated logs were also placed in this class. Whenever the major divisions appeared to be reasonably well subdivided by the driller the logs were classed as differentiated. Seven types were recognized in differentiated logs, namely: gravel, tight gravel, sand, tight or fine sand, gravelly clay, sandy clay and clay.

The specific yield values assigned to these various types of materials in well logs were derived from the specific yield values of Lines 2–5, Table 5.

Yield values for the materials designated in undifferentiated logs were obtained by combining the specific yield values for the subdivisions of the differentiated logs into their respective major divisions (gravel, sand or clay) in the ratio that the percentages of the combined parts bore to each other. Thus undifferentiated gravel includes gravel and tight gravel, undifferentiated sand includes sand and tight or fine sand and undifferentiated clay includes sandy clay, gravelly clay and clay. Generally several groups of wells within areas of similar material were combined to obtain the values that were applied to the undifferentiated well logs.

Table 5 shows the values for unweathered buried gravel to vary between 13 and 25 per cent, and the weathered gravel values to vary correspondingly. The actual value assigned to differentiated gravel for a particular well group was taken from the map (Plate F), which shows contours of estimated equal specific yield for unweathered subsurface gravel in the South Coastal Basin.

Computation of Storage Capacity in the Ground Water Basins.

The detailed descriptions of the ground water basins in the following chapters include specific yield values and storage capacity estimates for each of the basins discussed. The method used to obtain them is outlined briefly as follows:

1. The total footage of each type of material recorded in each vertical interval, for the well log group or composite log (page 112), was reduced to feet per hundred and multiplied by the respective specific yield values assigned to the different grades of materials. The sum of these products divided by 100 is the specific yield for the vertical interval. In other words, the specific yield is the percentage of drainable voids in the soil column.

2. The well log groups were divided into 50 foot vertical intervals where logs were abundant, into 100 foot intervals where logs were less abundant, and into greater intervals or were not divided at all where logs were scarce. In all cases the attempt was made to average sufficient footages to obtain a representative figure in order to discount the erratic results obtained from individual wells. The base used for the vertical interval was the surface, and the depth intervals represent zones parallel to the general alluvial surfaces. Irregularities due to dissection of the alluvial surfaces were discounted.

3. In order to convert the specific yield values from the well log groups to storage capacities of volume units, the values determined for the well groups were plotted on a series of maps, each map representing a certain depth zone. The values were plotted at the centers of gravity of the log groups. Contours of specific yield were drawn from these data, one set for each depth zone.

4. An area grid was superimposed upon these maps. This grid was based upon the three minute U. S. Geological Survey Quadrangles of Los Angeles County, the same grid being projected to cover the area outside the county. The area units were one-hundredth of a three minute sheet or slightly more than 252 acres each.

5. A tabulation was made showing for each area unit the following: (1) the average elevation of the bottom of the depth interval; (2) the specific yield interpolated from the map; (3) the area of the unit or fraction within the basin; and (4) the interpolated specific yield multiplied by the average area of the vertical interval, divided by 100. This last value represents acre feet of storage capacity or yield per foot depth, for the unit between the average elevations of the top and bottom of the respective vertical interval.

By using the same area grid the average elevation of the water table in each unit is interpolated from water table contours, and changes of elevation of the water table are determined in a like manner. The change of water table elevation in feet multiplied by the acre feet per foot (4) within the vertical interval where the change occurred gives the change of storage within the area unit.

Specific Yield Contours on Plate E in Pocket.

The storage capacity tabulation outlined above was thought to be too detailed and to require too much data to be practical for general use, and therefore it is not presented herein. However, an attempt has been made to present in a simpler form a usable set of specific yield contours on Plate E for each basin. Since the specific yields vary vertically as well as horizontally, it was necessary to draw contours which would apply to a zone with limited thickness. In order to do this, the water table of January, 1933 (Plate E), was used as a base, and from this base two theoretical water tables were worked out; one averaging 50 feet above the 1933 base, and the other averaging 50 feet below, except in those basins where the water table as of that date was less than 50 feet below the surface, or bedrock less than 50 feet below the water table as noted in Table 1, and in the detailed descriptions in the following chapters.

Where data were lacking, or where it was thought that probable fluctuations would approximately parallel the base water table, the hypothetical water tables limiting the zone were made parallel to the base.

In most cases, however, the zone both above and below the 1933 water table was made to vary in thickness according to the relative probable fluctuations in different parts of the basin. Thus, at the lower ends or outlets of some of the basins where there is little or no fluctuation of the water table, the zones are from zero to a few feet thick. The thickness was increased toward the central and upper margins, where fluctuations of the water table are greater, and in some basins the maximum thickness of the zone exceeds 200 feet. This zone though thick enough to include most storage changes, is not so thick that large inaccuracies are apt to result from vertical variations of specific yield within the zone.

By applying the differences in elevation between the base and the upper and lower limits of the zone, in the individual area unit, to the tabulation of storage capacity described above, the average specific yield for the zone was determined for each area unit and at the same time the storage capacity was determined for the zone in each unit. The specific yield values were plotted on a map and contoured. These are the contours of specific yield shown on Plate E.

The storage capacities for the area units within the zone were added in each basin, giving the storage capacity for the zone averaging 100 feet thick above and below the water table of January, 1933. In working these figures out, the storage capacity of the 50 foot zone above the base was determined separately from that of the 50 feet below, but in most cases the difference between the two was not significant. These storage capacity figures together with a discussion of their significance is included in the following chapters of detailed descriptions of the ground water basins.

SUMMARY

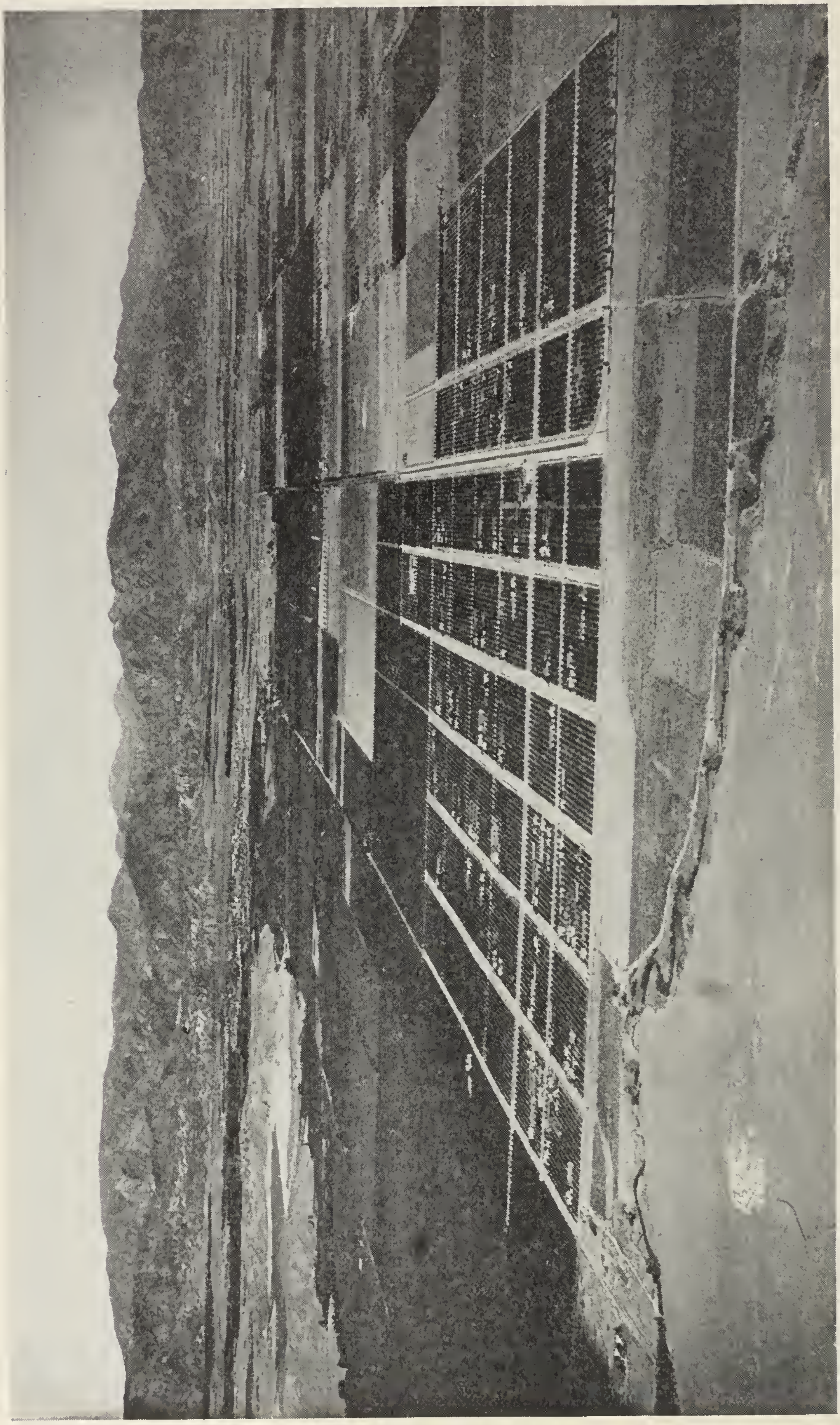
The unaltered materials upon the alluvial cone surfaces were studied in detail. Distribution of the various types (sands, gravels and clays) was noted, and the water-yielding properties were estimated by field and laboratory investigation. The water-yielding properties of these unaltered materials were classified according to coarseness, the maximum 10 per cent grade size being used as an index of coarseness.

The nature and amount of alteration that the water-producing deposits have undergone was studied, and the effect of this alteration upon the specific yield was evaluated. All subsurface materials were considered to have undergone some alteration.

It was not possible to determine experimentally the water-yielding properties of the buried materials (which are tapped by wells), and, therefore, specific yield values were assigned to these materials as reported in well logs by modifying the surface values to take into account the alteration of the strata logged. The values were varied also according to the probable average coarseness of the deposits.

The well logs were combined in groups of several logs and averaged, making composite logs which were used with the estimated specific yield values to compute groundwater storage capacities in the South Coastal Basin.

PLATE XIV



Looking east across northern San Fernando Valley. San Gabriel Mountains at left in distance. Verdugo Mountains at right in distance.

Spence Airplane Photo

CHAPTER IV

SAN FERNANDO VALLEY BASINS

San Fernando (1)*

Sylmar (2)	Tujunga (3)
Pacoima (4)	Verdugo (5)

San Fernando Valley is an alluvial plain about 23 miles long and half as wide. Its surface area exclusive of Verdugo Basin (Plate E) is 113,100 acres or 177 square miles. Little is known of the depth of pervious fill except in the southwest part of the basin where it is but a few hundred feet. It deepens toward the east and may reach 1000 feet depth near the east end of the basin. The Quaternary alluvial fill in the northern part of the area is underlain by water-bearing Fernando beds (Plate D, sections BC and EF). The maximum depth of these deposits is unknown but in most places is greater than the usual depth to which water wells are drilled. The water-bearing deposits of San Fernando Valley are underlain principally by Fernando shale, and Modelo shale and hard sandstone.

San Fernando Valley is connected by pervious alluvial fill with San Gabriel Valley through Verdugo Basin at the northeast end of the area. Bedrock hills protruding through the alluvium almost separate the two valleys where they join at the east end of Verdugo Basin. The ground water divides at this point and there is no underflow from one valley to the other.

San Fernando Valley is also connected with the Coastal Plain by the pervious fill in the Los Angeles River Narrows. The depth of this fill is 100 to 150 feet where the channel is narrowest. Underflow from San Fernando Valley and surface drainage of the Los Angeles River escape through these narrows. An excess of ground water in San Fernando Valley appears as rising water and is diverted from the channel at a point near the head of the narrows by Los Angeles City.

San Fernando Valley proper is simple structurally and is occupied by San Fernando Basin. Faults and bedrock barriers cut the northeast re-entrants of the valley into several small basins. Four of these subdivisions were included in the study. They are: Sylmar, Pacoima, Tujunga and Verdugo basins (Plate E).

SAN FERNANDO BASIN

Location and General Description.

San Fernando Basin, which occupies all of the valley south of the town of San Fernando, has a surface area of 96,200 acres. It is separated from the minor basins to the northeast by a high partially buried bedrock rim along the northeast side of the fault zone, which

* Numbers in parentheses are index numbers of basins as shown on Plate E in pocket.

runs along the northeast edge of the valley, to the town of San Fernando, and west of that point to the hills by an anticline which brings nonwater-bearing Fernando beds practically to the surface (Plates A and E).

No faults or other structures which have an effect upon the movement of the ground water cut through the central part of the basin, but several faults and folds are prominent in the alluvial fill around the margins (Plate A). None of these form important ground water barriers. A series of folds in the water-bearing Saugus formation plunges into the basin from the northwest and there affect the overlying Quaternary alluvium slightly. They have no apparent effect on the movement of ground water, however.

Character and Depth of the Bedrock Floor.

The bedrock floor slopes east and north from the depth of zero to a few hundred feet in the western and southwestern part of the basin, and to an unknown depth in the north and northeast part. It is known, however, to be more than 500 feet deep over the greater part of this area. The basin is underlain in the southern and southwestern part by Modelo shales interbedded with occasional hard sandstones and farther north, no doubt Fernando shales form the floor of the basin.

Character of the Water-bearing Series.

In San Fernando Basin there are two series of water-bearing deposits. The older, Saugus formation, is a series of folded alluvial deposits which underlies the later series, Quaternary alluvium, in the northern part of the basin. Elsewhere in the basin the Quaternary alluvium is the only water-bearing formation.

The Quaternary alluvial fill of San Fernando Basin has been derived from two types of material. West of the vicinity of San Fernando Creek local streams from the hills around the western part of the basin have deposited debris from sedimentary rocks of that region. East of San Fernando Creek, Pacoima Creek and Tujunga River have deposited alluvial cones which consist almost entirely of crystalline (Basement Complex) debris from the San Gabriel Mountains to the north. There is a fringe of similar material also along the northeast margin of the basin deposited by the smaller streams which drain the southwest slopes of the Verdugo Mountains.

Well logs show the western part of the basin to have 78.7 per cent clay, 2.1 per cent sand, and 19.2 per cent gravel. Although the smaller streams of this area probably bring down considerable fine material, the low percentage of sand compared to gravel indicates that the clays are due principally to decomposition of the deposits. These sedimentary materials probably break down more readily under the influence of weathering than do the crystalline rocks. In the eastern part of the basin where the large streams bring down coarse crystalline debris, well logs show 50 per cent clay, 5 per cent sand, and 45 per cent gravel. These deposits were originally coarser than those farther west and apparently do not break down as quickly through weathering. Deposition has probably been more continuous in the eastern area also.

The Saugus formation could not be distinguished from the Quaternary alluvium in the few well logs available in the northern part of the basin.

Comparatively little is known about the average coarseness of gravels in the western part of the area. Very few gravel beds are exposed at the surface and data from wells are meager, but on the basis of information available, the maximum 10 per cent grade size is estimated to vary from 1¼ to 2½ inches around the margins to ⅝ to 1¼ inches in the south central part. The specific yield values assigned to unweathered gravels for this area varies correspondingly from 16 and 17 per cent around the margins to 22 per cent in the central part.

Gravels of the large streams in the eastern part of the basin are much coarser. Gravel pits expose boulders up to two feet in diameter in the northeast part. The maximum 10 per cent grade size is estimated to vary from 5 to 10 inches at the northeast corner of the basin and along the northeast margin to 1¼ to 2½ inches along the southern margin, giving specific yield values for unweathered gravel varying from 14 per cent at the northeast edge of the basin to 20 per cent in the southwestern part.

Specific Yield and Storage Capacity of the Basin.

On the basis of the above gravel yield values and well log averages, computations of storage capacity were made for a zone averaging 100 feet thick above and below the water table of January, 1933. The computed storage capacity of this zone is 817,000 acre feet. This zone, which was taken between two theoretical water tables at approximately equal distances above and below the water table of January, 1933, has a minimum thickness of zero to ten feet along the Los Angeles River and increases to a little more than 200 feet in the northeast part of the basin in the Pacoima and Tujunga cones area. In the western part of the basin the zone varies from practically nothing along the Los Angeles River to from 80 to 120 feet thick along the northwest and north margins.

Contours of specific yield (Plate E) for this zone show the highest yields to be in the eastern and southeastern parts of the basin where a peak of about 16 per cent is reached. The yield decreases to about three per cent along the south and west margins, and to seven and eight per cent along the north and northwest margins of the basin.

Ground Water in San Fernando Basin.

Percolation of rainfall and run-off from the surrounding hills and mountains, together with water imported from Owens Valley through the Los Angeles aqueduct, are the main sources of ground water in San Fernando Valley. The ground water moves southerly over the bedrock rim from the minor basins into San Fernando Basin, and easterly from the western part of San Fernando Basin, converging toward the southeast corner where the surplus escapes as underflow or rising water.

Both the annual fluctuation of the water table and the long period rise and fall of the water table in the western part of San Fernando Basin is slight. The record of well No. A–15,* near Aliso Creek, shows an annual fluctuation of from one to five feet since 1920 with evidence of small direct recharge during and immediately following

* Division of Water Resources Bulletin 39, p. 14, and Bulletin 39-A, p. 4.

winters of heavy rainfall. During the period from 1920 to 1933 the water table rose about five feet. Other well records to the southwest indicate a drop there of similar proportions during the same period. The slight annual and long period fluctuations of the water table in this area are due to the relatively slight recharge and draft upon the basin compared to its storage capacity. The small slope of the water table in spite of the tight character of the material reflects this same condition.

Both the annual and long period water level fluctuations in the eastern part of the basin are greater than those in the western area. The record of well No. A–40 * shows an annual fluctuation ranging from about five feet to thirty feet during the period from 1920 to 1933. During the first half of 1922 there was a rise in the water table recorded by this well of a little more than 30 feet. The water levels in this and other wells in the eastern part of the basin were only a few feet lower in January, 1933, than in January, 1921. Although the wells show the direct effect of recharge of Tujunga River and Pacoima Creek, the rise and fall of the water table is controlled to a large extent by importation and exportation of water by Los Angeles City. Spreading of aqueduct water from Owens Valley on Pacoima and Tujunga cones since extensive spreading began in the latter part of 1930 has raised the water table in that area.

Wells throughout the San Fernando Valley generally do not show strongly the effects of pressure and therefore the water levels in wells represent the surface of a free water table.

MINOR BASINS OF SAN FERNANDO VALLEY

Location and General Description.

The alluvial area northeast of San Fernando Valley proper is divided into four minor basins: Sylmar, Pacoima, Tujunga and Verdugo basins. These basins lie at the base of the San Gabriel Mountains and are in part cut off from San Fernando Valley by the Verdugo Mountains structural block.

The southeastern part of the area is occupied by Tujunga and Verdugo basins. Tujunga Basin, the western of the two, has a surface area of 7330 acres, and Verdugo Basin, 3840 acres. The bedrock floor of these two basins is a long narrow trough, open at the west end, and near the southeast end where Verdugo Canyon forms the outlet. In Tujunga Basin the axis lies near its north side and the floor has a depth of about 150 feet. In Verdugo Basin the bedrock floor is apparently the buried upper portion of Verdugo Canyon (Plate A). Due to the steep southwest slope of the alluvial surface in Verdugo Basin, the thickness of fill is greater near the northeast margin than along the axis of the bedrock canyon. The basin depth increases from about 150 feet at its narrowest point near Glendale to 350 and 400 feet in the northeastern part. So far as it is known, the floor of Verdugo Basin is composed of Basement Complex like that exposed in the mountains on either side. The floor of the eastern part of Tujunga Basin probably is also Basement Complex, but from the vicinity of Sunland west, hard sandstones and shales of the Modelo formation underlie the

* *Op. cit.*, Bulletin 39, p. 22, and Bulletin 39-A, p. 5.

alluvial fill (Plate D, section EF). Near the mouth of Tujunga Canyon a belt of Fernando shale underlies the alluvial fill (Plate A).

Sylmar and Pacoima basins occupy the northwest part of the area of minor basins. They are presumably separated by the buried extension of the fault along the northeast side of San Fernando Valley. Sylmar Basin lies to the west and Pacoima Basin to the east. The surface area of Sylmar Basin is 6700 acres, and of Pacoima Basin is 2870 acres. Pacoima Basin is separated from Tujunga Basin by the contact between water-bearing Fernando (Saugus) beds and nonwater-bearing Fernando (Pico) beds which crop out east of the alluvial fill and lie near the surface under the Quaternary alluvium. Sylmar Basin is separated from San Fernando Basin in a similar manner where nonwater-bearing Fernando beds lie near the surface along an anticlinal axis (Plate A).

The northern boundary of these basins is formed by a thrust fault zone which separates nonwater-bearing Tertiary sediments and crystalline Basement Complex from the water-bearing deposits. The western boundary of Sylmar and the eastern boundary of Pacoima basins are arbitrary lines through the water-bearing deposits. The western boundary of Sylmar Basin runs northwesterly and southeasterly through lower and upper San Fernando reservoirs. It is thought that the water table is nearly constant along this line, being controlled by surface water in the reservoirs. The eastern boundary of Pacoima Basin is thought to approximate a ground water divide. Little is known about ground water conditions in this area east of Pacoima Wash, however. The water-bearing areas east and west of these basins are included in "Miscellaneous Basins" (Plate E), and no study of them was made.

As shown on the geologic map (Plate A), there are two series of water-bearing beds in Pacoima and Sylmar basins; the Quaternary alluvium and the folded Saugus formation beneath. The later beds have been so deeply infolded and downfaulted along the northern boundary that the depth of the basin, although not known, is too deep to be of direct concern in storage capacity or water supply problems. The nonwater-bearing Fernando (Pico) shales and silts which underlie the Water-bearing series form the floor of the basin in this area.

Character of the Water-bearing Series.

The Water-bearing series in different minor basins is quite variable, due to the different sources of the deposits. The percentage of clay, sand and gravel for each of the basins is shown in Table 6.

TABLE 6

COMPOSITION OF THE WATER-BEARING SERIES IN THE MINOR BASINS OF SAN FERNANDO VALLEY

Basin	Percentage		
	Clay	Sand	Gravel
Sylmar	62.5	1.1	36.4
Pacoima	29.0	0.0	71.0
Tujunga	21.3	3.4	75.3
Verdugo	77.1	0.0	22.9

One feature characteristic of all four basins is the low percentage of sand. This is characteristic of foothill basins and indicates that the material originally deposited was principally gravel. The clays have been formed by weathering of the coarser deposits.

In Sylmar and Pacoima basins no difference could be detected between Quaternary alluvium and underlying Saugus beds from well logs, and therefore it was necessary to average materials of the two formations together. The higher percentage of gravel in Pacoima Basin is probably due to the proximity of Pacoima Creek which has deposited more continuously upon its cone than the small streams which have deposited the alluvial fill of Sylmar Basin. It is not known whether similar conditions existed during deposition of the Saugus beds. If not, the indications are that the wells, which are several hundred feet deep in Pacoima Basin, penetrate principally Quaternary alluvium.

There is a striking similarity between deposits of Pacoima and Tujunga basins. Both are high in gravel and low in clay content. In the case of Tujunga Basin the high gravel content is due to the confined character of the cone, which has prevented long periods of weathering upon surfaces undisturbed by stream action. In such an area when surfaces do become deeply weathered they are apt to be removed by lateral planation before they are buried by fresh deposits. Although this is less true of conditions in Pacoima Basin, the location of the basin at the head of Pacoima Cone has created a similar condition unfavorable to the accumulation of weathered materials. In Verdugo Basin the conditions are reversed. The steep cones with small headwater areas have been dissected many times, allowing the surfaces to become weathered. Thus conditions in this basin have been ideal for the accumulation of weathered clayey deposits.

In all but the Sylmar Basin area, gravels are very coarse. Boulders from three to four feet in diameter are common in Pacoima, Tujunga and the northeastern part of Verdugo basins. Although coarseness decreases sharply in these basins away from the canyon mouths, especially in Verdugo Basin, the average maximum 10 per cent grade size is thought to be 2½ to 5 inches or greater, except locally and in Verdugo Canyon in the southeastern part of Verdugo Basin. Therefore, the minimum specific yield of 13 per cent was assigned to the unweathered gravels of these three basins except in the southeastern portion of Verdugo Basin where it was increased to 15 per cent. In Sylmar Basin there are no large streams nor streams with steep cones, therefore the Quaternary alluvium is less coarse than in the other basins and outcrops of the Saugus formation around the boundary do not show coarse boulder beds either. However, absence of sand in any quantity and surface exposures of gravel in the northern part indicate that the gravel deposits, though not as coarse as those of the other basins, are nevertheless coarse and the maximum 10 per cent grade size was estimated to be 2½ to 5 inches at the heads of the cones along the canyon mouths, and to decrease to a little less than 2½ inches at the south margin. On this basis yields of 13 to 15 per cent were assigned to unweathered gravels.

Specific Yield and Storage Capacity.

The computed storage capacities of the zones averaging 100 feet in thickness above and below the water table of January, 1933, in the minor basins are as follows: Sylmar, 44,000 acre feet; Pacoima, 23,000 acre feet; Tujunga, 43,000 acre feet; and Verdugo, 17,000 acre feet. Shallow bedrock in Tujunga and Verdugo basins reduces the storage capacity materially with depth. In both Tujunga and Verdugo basins, approximately 54 per cent of the computed storage capacity is in that portion of the zone above the water table, and 46 per cent in that portion below. In Sylmar and Pacoima basins the storage capacity is slightly greater in the 50 foot average zone below the water table than in the similar zone above.

The zone for which storage capacity was computed had a minimum thickness of 45 feet in Sylmar Basin at the southeast corner. Most of this thickness was below the water table at this point. The thickness increased toward the northern margin to a maximum of about 200 feet. In Pacoima Basin the zone was 100 feet thick throughout. In Tujunga Basin it increased from about 40 feet in the eastern part to 130 feet in the western part. The zone was 100 feet thick throughout Verdugo Basin except along the margins where cut off by sloping bedrock.

Specific yield contours (Plate E) show the yield in Sylmar Basin to vary from 5 to 9 per cent, in Pacoima Basin from 7 to 11 per cent, and in Tujunga Basin from 10 per cent at the southwest margin to 8 per cent at the east end. The specific yield of Verdugo Basin increases from three per cent along the northeast margin up to 12 per cent within the canyon, dropping to 10 per cent toward the lower end.

Ground Water in Sylmar Basin.

The ground water in Sylmar Basin moves southerly and southeasterly from the canyon mouths along the northern margin and southwesterly from Pacoima Basin. In January, 1933, the water table on the east side of the San Fernando reservoirs was slightly higher than the water surfaces in the respective reservoirs. There was, therefore, probably a slight contribution to the reservoirs from the underground basin. This condition would be reversed should the water table drop below the reservoir water surfaces.

The main body of ground water moves southeasterly through the basin, converging toward the south margin as the basin narrows. It is crowded to the surface at the south margin where the Fernando shales which crop out to the west approach the surface. Slight artesian pressure and rising water occur in the southwestern part of the basin.

Water level records in this basin are inadequate for the determination of the nature of fluctuation and recharge.

Ground Water in Pacoima Basin.

Pacoima Creek is the principal source of ground water in Pacoima Basin. The ground water moves southwesterly and westerly through the basin, the underflow escaping mainly to the west through the fault into Sylmar Basin. Some ground water escapes to the south over the bedrock barrier, but the amount is probably small since the cross-section of pervious material above the bedrock is not large.

Well records in Pacoima Basin are so scattered that they merely suggest the nature of water table fluctuations there. The record of well No. A-4,* near the center of the basin, though incomplete, dates back to 1902. In dry years the water level in this well shows very little fluctuation, but in years of excessive rainfall and run-off the fluctuation is large, due to the large direct recharge from Pacoima Creek. This well showed a water level rise of 37 feet from January to May, 1932. In the southeast corner of the basin where Pacoima Creek wash cuts through the bedrock, the water table is near the surface at all times, remaining nearly constant.

The water table in January, 1932, was at approximately the same level as it was in 1904. There is, therefore, apparently an excess of ground water in this basin that wastes underground.

Ground Water in Tujunga Basin.

Tujunga Basin is one of high permeability which receives a large direct recharge from Big and Little Tujunga rivers. Consequently, the annual water table fluctuations are large. The excess of ground water discharges during the summer months by underflow into San Fernando Basin. In 1932 water levels in different parts of the basin rose from 20 to 30 feet during the winter and spring, but the net gain at the end of the year was only a few feet. No long period record is available in the basin, but it is clear from the large recharge during wet years and the comparatively small annual differences in the water table that the basin has a large excess of ground water which wastes underground over the bedrock rim along the southwest margin, into San Fernando Basin.

Ground Water in Verdugo Basin.

Percolation of run-off from the streams entering the basin from the northeast is the principal source of ground water in Verdugo Basin. The ground water moves southwesterly at the divide from the northwest margin of the basin, southerly from the northeast margin and southeasterly from the ground water divide at the southeastern boundary of the basin, converging toward Verdugo Canyon through which the underflow passes. When there is an excess of ground water at the head of Verdugo Canyon it rises to the surface and flows through the canyon.

Water levels in Verdugo Basin generally show annual fluctuations of only a few feet. The recharge occurs directly from run-off, and in years of excessive run-off, water levels rise sharply. Well records do not show important pressure effects. The rise and fall of the water table, therefore, measure replenishment and depletion of storage.

The available water level records in the basin are not sufficiently complete to permit an estimate of the decline over a period of several years.

* Division of Water Resources Bulletin 39, p. 10, and Bulletin 39-A, p. 3.

CHAPTER V

SAN GABRIEL VALLEY BASINS

Monk Hill (7)*	Upper Canyon (9)	San Dimas (13)
Raymond (8)	Lower Canyon (10)	Foothill (14)
Pasadena Area (8a)	Glendora (11)	Puente (15)
Santa Anita Area (8b)	Way Hill (12)	San Gabriel (6)

San Gabriel Valley is the alluvial plain that lies between the Whittier Narrows and the San Gabriel Mountains (Plate XV). The surface area of the ground water basins that lie beneath the valley floor is approximately 195 square miles, or 120,560 acres. The maximum depth of pervious fill is unknown, but exceeds 2000 feet. Beneath the greater part of the valley the depth of fill is far greater than the economic limit from which ground water can be lifted, and is therefore not of direct significance in the determination of the quantity of available water in storage. However, the irregular impervious floor of the basin lies within a few hundred feet of the surface beneath a considerable portion of the marginal areas, and, in these areas, is an important limiting factor to the ground water storage capacity.

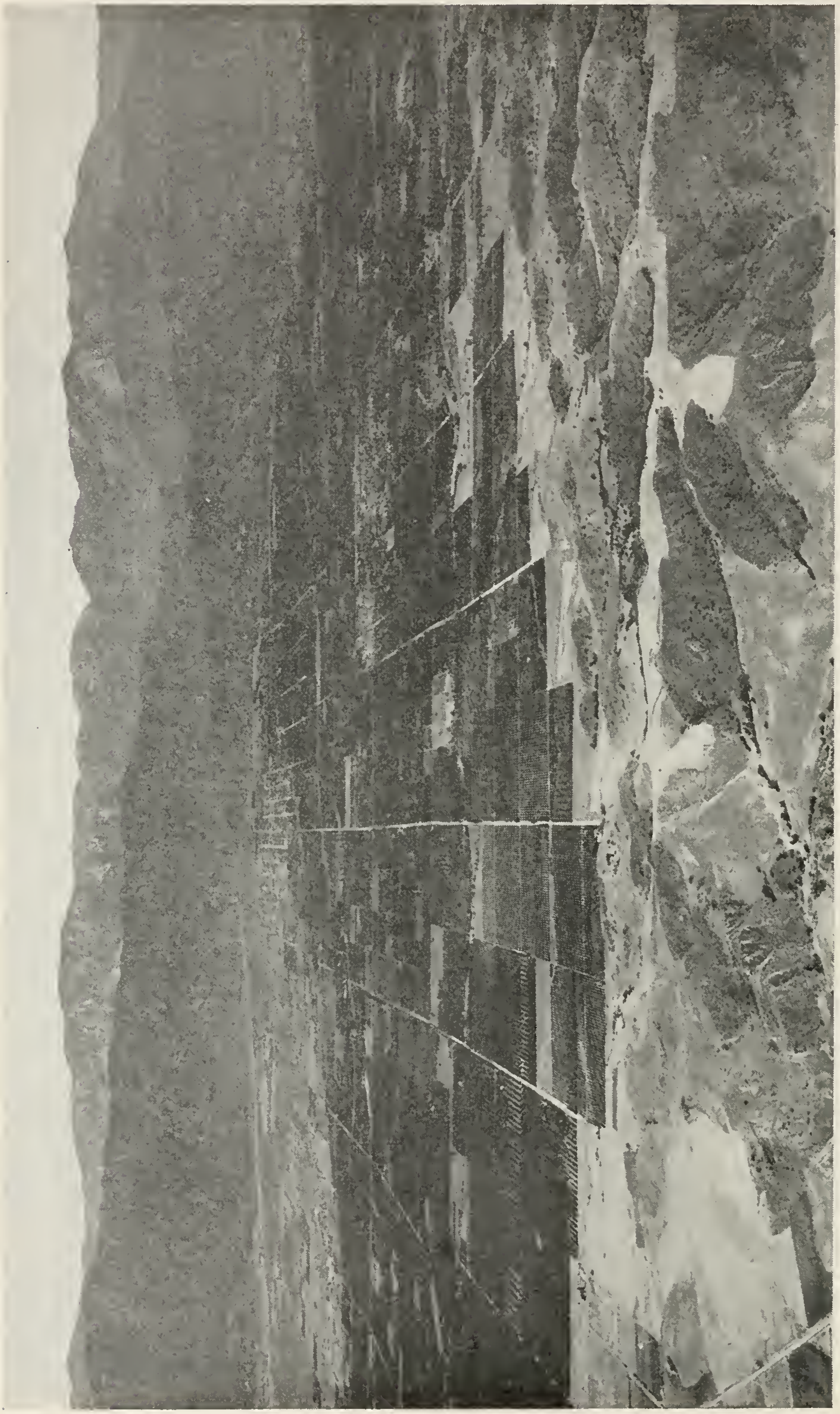
San Gabriel Valley is connected by narrow necks of pervious alluvial fill, with the three adjacent alluvial plains, San Fernando Valley to the west, Upper Santa Ana Valley to the east, and Central Coastal Plain to the south.

Percolation of stream run-off from the San Gabriel Mountains, together with percolation of rainfall upon the valley floor, is the principal source of the ground water. Relatively little water is added by run-off from the intermediate hills around the southwestern and southeastern margins of the basin. Underflow from Upper Santa Ana Valley normally enters San Gabriel Valley at two points. In the past, a relatively large underflow from the Pomona Basin area of Upper Santa Ana Valley has crossed the subsurface bedrock divide between La Verne and San Dimas, and flowed into San Gabriel Valley. Gradual lowering of the water table in the Pomona Basin area has greatly reduced or cut off this underflow. Underflow from Upper Santa Ana Valley reaches San Gabriel Valley also through San Jose Valley. The total supply from Upper Santa Ana Valley through these two ground water gaps forms a relatively insignificant part of the total supply, and being subject to water table fluctuations in Upper Santa Ana Valley, is an uncertain quantity which may be cut off by still further lowering of the water table in the future.

Within the valley itself, the ground water from all parts converges toward the Whittier Narrows. The surplus which does not escape underground through the narrows rises to the surface upstream

* Numbers in parentheses are index numbers of basins as shown on Plate E in pocket.

PLATE XV



San Gabriel Valley looking north. Puente Hills in foreground, San Gabriel Mountains in background.

Spence Airplane Photo

where a part is consumed by evaporation and transpiration and the remainder flows through the narrows as surface water.

There are no other ground water gaps of importance through which underflow from the basin occurs. The alluvial fill in the gap west of South Pasadena, where Arroyo Seco Wash runs out of the valley, is too shallow to permit escape of appreciable quantities of ground water. There are several small gaps in the hills between Arroyo Seco and Whittier Narrows through which local surface run-off from the vicinity of Alhambra drains, but in none of these is the bedrock deep enough to permit ground water to escape. However, the broad saddle about two miles northwest of Whittier Narrows is a syncline in which pervious gravels have been folded down below the water table of San Gabriel Basin (Plate A) and it is probable that there is some underflow through this.

San Gabriel Valley contains 10 principal basins, which are designated as follows: San Gabriel, Monk Hill, Raymond, Upper Canyon, Lower Canyon, Glendora, Way Hill, San Dimas, Foothill and Puente basins.

RAYMOND BASIN AREA

Location and General Description.

The Raymond Basin area occupies the northwest part of San Gabriel Valley and is separated from San Gabriel Basin by Raymond fault (Plate A), which has produced the well known "Raymond Hill Dike." It is bounded along the west by San Rafael Hills and on the north and northeast by the San Gabriel Mountains. The area is 35.8 square miles, or 22,900 acres.

Three subdivisions are recognized within the area on the basis of structure and behavior of the ground water. They are: Monk Hill Basin, and the Pasadena and Santa Anita areas of Raymond Basin (Plate E, Nos. 7, 8a and 8b, respectively).

Raymond fault forms a barrier to the movement of ground waters so effective that an artesian area existed along the north side of the fault before the water table was lowered by pumping. At present, the water table north of the fault stands from 200 to nearly 300 feet above that south of it.

At the western edge of Raymond Basin where displacement of the bedrock by fault is measurable, the north side appears to have been upthrown several hundred feet. The uplifted bedrock on the north side of the fault forms an impervious barrier that extends eastward into the basin from the west margin. Between Raymond Hill, near Fair Oaks Avenue, and the western edge of the basin, several hills protrude through the alluvium and between these hills the maximum depth to bedrock is probably nowhere greater than 150 feet. Raymond Hill is the most easterly surface exposure of bedrock along the dike, and a short distance to the east the bedrock both north and south of the fault drops away steeply. Bedrock has been reported in only one well near the fault and more than one mile east of Fair Oaks Avenue. From this well, No. C-120 (Plate E in pocket), near San Gabriel Boulevard one-third mile north of the fault, shale was reported at the depth of 855 feet. Many other wells several hundred feet deep have failed to reach the base of the water-bearing materials. It becomes apparent, therefore, that between Raymond Hill and the east edge of the basin, Raymond fault itself and not bedrock forms the barrier that has produced artesian conditions north of it. The fault is a narrow crushed zone cutting through the alluvium, along which clay gouge has developed. It is this gouge, together with deformation and displacement of the pervious beds, that forms the dike. That this fault barrier is slightly permeable is attested by the fact that the water table south of the fault slopes away from it toward the cenral part of San Gabriel Valley. This ground water dike is most permeable in the vicinity of Santa Anita Wash, where artesian pressure is lacking north of the fault and where there is a difference in water levels on opposite sides of only about 200 feet. Probably the greater permeability of the fault plane in this region is due to the fact that it traverses the relatively fresh coarse gravels of Santa Anita Cone.

The western and northwestern boundary of the Raymond Basin area is formed by the impervious slopes of the San Rafael Hills west of Pasadena, which pass beneath the alluvium to form the basin floor. Monk Hill near the northern part and Raymond Hill at the southern edge are eastward extensions of these hills that protrude through the alluvium.

The north and northeast boundaries of the area are formed by a series of faults of the Sierra Madre system, along which the Basement Complex of the San Gabriel Mountains is faulted up against the alluvium. For the most part these faults are concealed beneath a comparatively thin mantle of alluvium that fringes the mountain base.

Monk Hill Basin lies between Monk Hill (Plate D, Section HI) and the northern margin of the area. It is an alluvium-filled trough, one to two miles wide and about six miles long, between the San Gabriel Mountains and San Rafael Hills, extending from the bedrock rim near Montrose southeasterly as far as Monk Hill. Beyond this point the trough opens out into the deeper Raymond Basin and loses its structural identity.

Character and Depth of the Bedrock Floor.

The few wells which have been drilled near the northern edge of the basin area indicate considerable depths of alluvium near the fault. One well, No. C-5a (Plate E) in the Arroyo Seco, one-third mile south of the fault that forms the north basin boundary, reached Basement Complex at the depth of 660 feet, the elevation of bedrock being 428 feet above sea level. From this evidence and from that of several other wells within one-half mile of the fault that do not reach bedrock, it appears that the down-faulted basin floor is covered by more than 500 feet of alluvium along at least a considerable part of its northern boundary.

The bedrock floor of the Raymond Basin area, where encountered by wells north of Eagle Rock fault (Plate A), has been found to be Basement Complex. In the comparatively narrow strip between Eagle Rock and Raymond faults, wells drilled through the alluvium have encountered cemented Tertiary conglomerates, sandstones and shales, which are at least in part of Topanga age. East of San Gabriel Boulevard and throughout a large part of the northern portion of the basin, apparently no wells have reached bedrock, and consequently the character of the basin floor is unknown in that part of the basin.

The depth of pervious fill in the Raymond Basin area is highly irregular, varying within the basin from zero to a known depth of 1220 feet. Contours drawn on the base of the water-bearing deposits (Plate A), show two bedrock prominences, the protruding surfaces of which form Raymond and Monk hills. Both of these prominences are eastward extensions of the San Rafael Hills and disappear toward the east.

The bedrock floor of Monk Hill Basin slopes down from the San Rafael Hills toward the down-faulted northeast margin of the basin and is lowest near the northeast edge. The alluvial surface slopes rather steeply south from the San Gabriel Mountains, and consequently the north-south cross-section (Plate D, Section H-I) of the basin shows the pervious fill to be in the form of a wedge, thickest against the fault and converging to a point at the southern margin. Both the surface and the basin floor slope down toward the southeast. The elevation of bedrock at the west end of Monk Hill Basin is 1600 feet above sea level. The bottom of a well which ended in alluvium north of Monk Hill has an elevation of only 210 feet. The basin probably becomes deeper to the east.

The Pasadena area lies south and east of Monk Hill Basin. There is a broad valley in the bedrock between Monk Hill and Raymond Hill that becomes deeper toward the east. The lowest point at which bedrock has been encountered south of Monk Hill was in well No. C-127, at the depth of 945 feet or 55 feet below sea level. Well No. C-52a, three miles southeast of Monk Hill, was drilled to the depth of 1220 feet or 430 feet below sea level, without encountering bedrock. Thus the eastern part of the basin is far deeper than the economic depth limit from which water can be pumped.

In the Santa Anita area, which forms the narrow eastern end of Raymond Basin, apparently no wells have reached bedrock. However, well No. C-110, 779 feet deep, penetrated alluvium to the depth of 117 feet below sea level. Several other wells were drilled to depths of more than 500 feet, in alluvium. It is thought, therefore, that the basin in this area is more than 500 feet deep throughout the greater part of its extent.

Character of the Water-bearing Series.

The alluvial fill of the Raymond Basin area is characteristic of the coarse deposits found in the small basins near the mountain margins. The gravels are coarsest at the base of the mountains where they contain boulders several feet in diameter, but even in the southern part of the basin sizes ranging from cobbles six inches in diameter to boulders 12 inches in diameter are not uncommon. There are practically no true sand beds in the northern part of the area, and over the entire basin the average sand content as determined from well logs is only 2.8 per cent. The deposits are characterized throughout by an abundance of weathered material. Decomposed yellowish gravels, clayey yellow and red gravels, and red or brown residual soil clays are the typical deposits. Both horizontal and vertical changes from gravelly to clayey material are sharp and erratic. Well logs show the distribution of these materials in Monk Hill Basin to be similar to the distribution in Raymond Basin. In Monk Hill Basin 48.3 per cent of the material is clay and gravelly clay; in Raymond Basin 48.5 per cent is clayey material. The sand content is negligible in Monk Hill Basin, and averages 3.7 per cent in Raymond Basin. The average gravel content is 51.7 per cent in Monk Hill Basin, and 47.8 per cent in Raymond Basin. With the exception of local areas near Raymond fault, the clays have all been developed by decomposition of the gravels since their deposition.

Unweathered gravels in Raymond Basin have been assigned specific yield values varying from about 20 per cent in the lower part of the basin to 13 per cent near the mountains. The distribution of these yield values, made according to estimated distribution of maximum 10 per cent grade size of gravel units, is shown on Plate E.

Specific Yield and Storage Capacity.

The storage capacity of the zone 100 feet thick, above and below the water table of January, 1933, was estimated for Monk Hill Basin to be 35,000 acre-feet, and for Raymond Basin, 146,000 acre-feet.

In the Monk Hill Basin the zone for which specific yield contours are shown (Plate E) is 100 feet thick over the entire basin, extending from 50 feet above the water table of January, 1933, to 50 feet below that water table. The lowest specific yield is about four per cent in the extreme northwest corner of the basin. Over the greater part of the basin it is nine per cent, but along the southern edge near Arroyo Seco, it rises to 11 per cent. The lower yield along the north margin is due to a high percentage of clayey material and tight gravel in that area. The low yield of 13 per cent assigned to the coarse gravel and boulder beds of Monk Hill Basin accounts in large part for the comparatively low specific values throughout the basin.

In the Pasadena area a similar zone 100 feet thick, 50 feet above and below the January, 1933, water table, was used over the whole basin for specific yield contours. The specific yield is irregular in this basin. However, it appears to be uniformly higher throughout the central part, the maximum there being a little above 11 per cent. The yield values drop sharply toward the eastern margin to about six per cent. There is a high percentage of tight clayey material in this area between the active Eaton and Santa Anita streams. The gradual trend toward higher yields from about eight or nine per cent at the north margin of the basin to 11 per cent at the south edge is due principally to the higher specific yield of the original gravels as the distance from the mountains increases.

In the Santa Anita area specific yield contours also represent a 100 foot zone from 50 feet above the January, 1933, water table to 50 feet below it. The specific yield rises sharply in this basin from six per cent at its western edge to a maximum of nearly 12 per cent in the vicinity of Santa Anita Wash. This sharp increase in specific yield is due to the high percentage of good gravel in the Santa Anita cone.

Ground Water in Monk Hill Basin.

The principal source of ground water in Monk Hill Basin is derived by percolation from Arroyo Seco Wash above Devils Gate dam. Smaller streams and rainfall percolation constitute additional supplies. The water table slopes steeply southeasterly from the northwest rim of the basin where its elevation in January, 1933, was between 1400 and 1500 feet, flattening in the vicinity of Arroyo Seco where its elevation was a little more than 900 feet. East of Arroyo Seco the water table rises very slightly toward the east and northeast, reaching a relatively flat water table divide, running northerly from Monk Hill to the north boundary of the basin (Plate E). This rather indefinite divide has been taken as the east boundary between the Monk Hill Basin and the Pasadena area of Raymond Basin. An examination of water level records for the years 1904–1905 * does not show this ground water divide, but rather indicates a gentle slope southeasterly from Arroyo Seco to about the position of the present divide, and a steep slope beyond that point. Since 1905, heavy pumping in the vicinity of Arroyo Seco has caused the water table there to drop about 50 feet, but at the east edge of the basin it has dropped only 16 feet, thus causing a reversal of gradient. It appears probable that under existing conditions, the only underflow out of Monk Hill Basin occurs through the sub-surface gap between Devils Gate and Monk Hill. The present water table elevation at the gap is about 900 feet. At that elevation the estimated width of the gap is 4000 feet and the depth about 150 feet. These figures are from the bedrock contours (Plate A) and therefore are only approximate.

Although nearly half the alluvial material in Monk Hill Basin is clayey, the ground water has an essentially free surface or water table which fluctuates directly according to the quantity of withdrawal or recharge. The residual clay which is the only type found in Monk Hill Basin, and which is common throughout a large part of the South Coastal Basin, does not occur in unbroken layers or strata like depositional clay deposited as blankets. Distribution of the decomposed reddish-brown clayey materials is erratic and discontinuous, consequently the pervious gravel beds are more or less interconnected throughout the alluvial fill and the ground water moves as a unit.

Recharge from winter rains begins almost immediately when run-off occurs and because of the relatively large watershed area compared to the basin area, the water table rises rapidly after heavy storms. The water level record of well No. C-6,† east of Devils Gate reservoir, shows a rise of about 50 feet in four months following the heavy storm in December, 1921. Similar but smaller rises have occurred in other years since 1922. In dry years the water table shows very little rise during the winter months. The seasonal decline of water levels due to pumping and underflow into Pasadena Basin generally begins about May first. Underflow through the Monk Hill gap decreases as the water table drops, with corresponding increase in the percentage of the annual supply retained in the basin. If the water table should be drawn below the elevation of the bottom of this gap (probably below 750 feet), the outflow would cease.

* Mendenhall, W. C., U. S. Geological Survey Water-Supply Paper 219, 1905.
† Division of Water Resources Bulletin 39, Map 1, 1932.

Ground Water in the Pasadena Area of Raymond Basin.

The principal sources of ground water in the Pasadena area are: (1) underflow from Monk Hill Basin, (2) direct percolation of run-off from the hills and mountains adjacent to the basin, and (3) direct percolation of rainfall and other water from the basin surface.

East of Monk Hill Basin, Eaton Wash is the only important drainage channel entering the basin. Arroyo Seco Wash along the west edge of the basin overlies pervious fill for a distance of about four miles, between Devils Gate dam and Colorado Street. Percolation takes place from the streambed throughout this distance when surplus water is allowed to discharge from Devils Gate dam.

The water table has a general slope toward the southeast, being highest in the vicinity of Monk Hill Basin and along the San Gabriel Mountain-front to the east. In January, 1933, water levels at the edge of Monk Hill Basin stood slightly above 900 feet elevation. They were lowest at Raymond fault, where the lowest levels were a little less than 500 feet elevation.

In the lower part of the Pasadena area, near Raymond fault, the ground water is under artesian pressure and water level changes in this area reflect pressure changes and do not measure direct changes of storage. Hydrographs of wells in this pressure area show water level fluctuations to be sharp and several times the magnitude of those a short distance outside the pressure area. Pressure well levels commonly fluctuate 20 to 30 feet during the year, while the corresponding water table fluctuations as measured by non-pressure wells are generally not more than 10 feet. The greater fluctuation of the pressure wells is due to transmission of pumping effects throughout the pressure area during the pumping season. The residual changes of level after the pumping season, as recorded from one year to the next, are comparable with those outside the pressure area, generally being 5 to 10 feet, and it seems probable that these changes represent approximate changes of storage.

The pressure area, as determined from the nature of water level fluctuations in wells, extends north from Raymond fault about one mile to the vicinity of California Street. It narrows toward the east to a width of about one-half mile at the eastern limit of the basin. This pressure area is caused by the combination of Raymond fault which seals off the gravels and the abundance of clayey material in the alluvium, which prevents the unrestricted rise of the ground water at the barrier. The distribution of clayey material is similar to that in Monk Hill Basin, but there the ground water dike is a buried ridge over which pervious gravels carry the underflow. North of the pressure region of the Pasadena area the ground water has a free surface and the recovery of static water levels after the pumping season is slight. Unlike Monk Hill Basin, the Pasadena area does not have a large direct supply from run-off, but is dependent in large part upon underflow from Monk Hill Basin for recharge. Consequently, recharge is delayed several months while Monk Hill Basin fills, and then only a part of the recharge of Monk Hill Basin is discharged into the Pasadena area. Because of this condition recovery of water levels, even in a year of excessive run-off such as 1922, is comparatively slight, and coming as it does late in the year it is masked by pumping effects.

Ground water escapes through the Raymond fault east of Raymond Hill and over the bedrock dike west of there into San Gabriel Basin, but the amount of underflow is not measurable. It decreases, however, as the difference in water levels on opposite sides of the fault decreases, and will cease to flow over the bedrock dike west of Raymond Hill if the water table drops sufficiently.

Ground Water in the Santa Anita Area of Raymond Basin.

The ground water supply in the Santa Anita area comes principally from the two Santa Anita canyons, and to a minor degree from underflow out of the Pasadena area. Rainfall percolation is an additional factor.

In January, 1933, the elevation of the water table at the western margin of the basin was a little more than 500 feet, and sloped eastward toward Santa Anita Wash where the water levels in wells stood at about 485 feet. The slope at that time is typical of the water table in this area. The comparatively steep gradient at the west boundary of the area is due to the relatively lower permeability at the west side of the area. The map shows a specific yield of six per cent at the west side and 12 per cent near Santa Anita Wash.

The artesian area north of the Raymond ground water dike, in the eastern part of the Pasadena area, ends at the western edge of the Santa Anita area where the permeability of the alluvial fill increases sharply. The Raymond fault, where it forms the south boundary of Santa Anita area, is a less effective barrier than it is farther west in the Pasadena area. The water table shows a difference of a little less than 200 feet elevation on opposite sides of the fault in the Santa Anita area, and farther west about 250 feet.

A study of several well records* in the Santa Anita area indicates a sharp seasonal fluctuation of 10 to 25 feet, or an estimated fluctuation of storage amounting to 2000 to 5000 acre feet. Recharge after heavy storms appears to have some effect on the water table within a month, but continues for more than a year, being evident again the following winter after the summer pumping season ends. The delayed recharge probably comes from the Pasadena area to the west and northwest and is retarded by the tight material between the two basins.

CANYON BASIN AREA

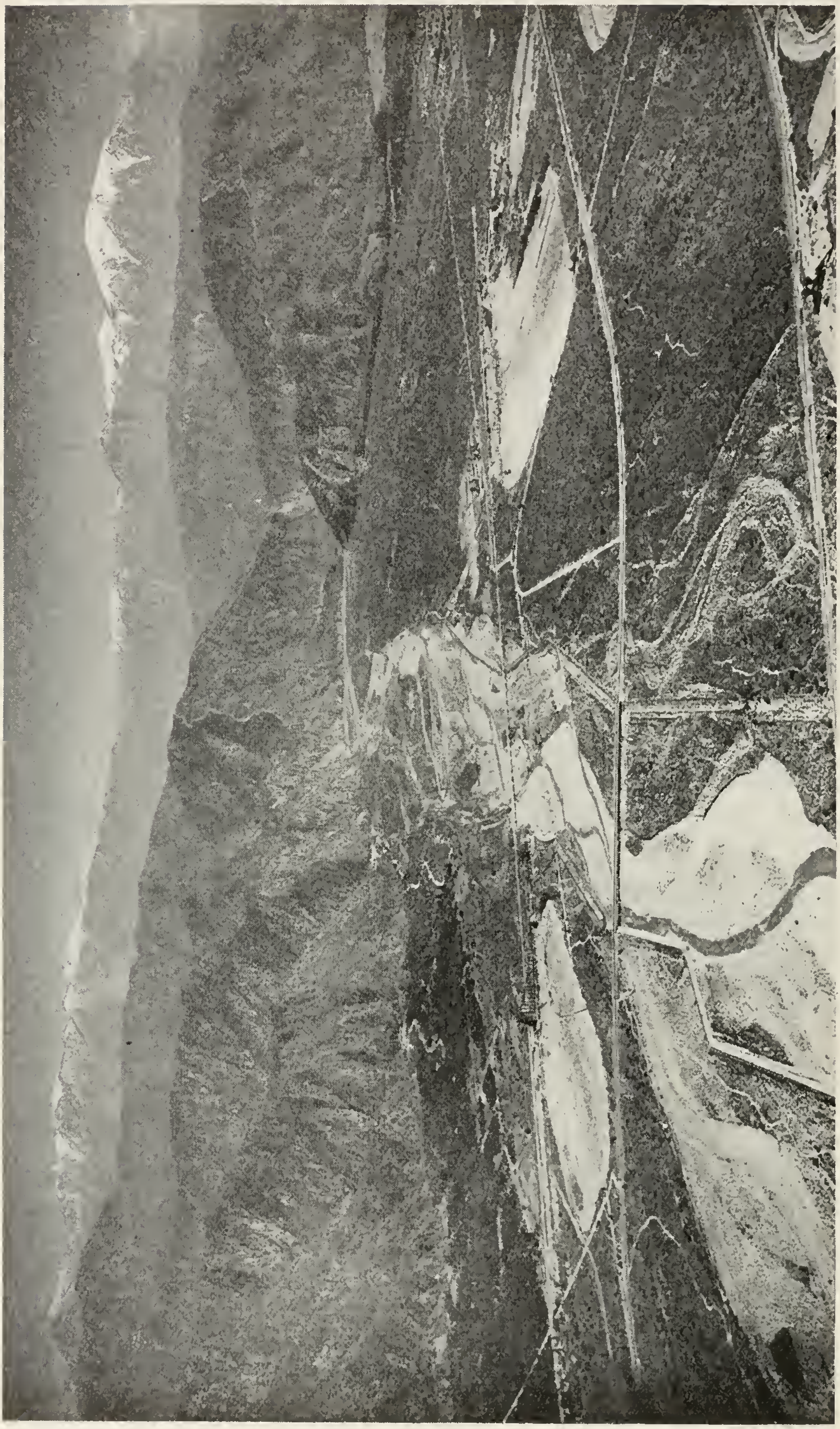
Location and General Description.

The Canyon Basin area occupies the triangular re-entrant of the San Gabriel Mountain-front at the mouth of San Gabriel Canyon (Plate XVI). Its area is about 2840 acres or 4.4 square miles and is separated in part at least from San Gabriel Basin by the southernmost of a series of faults of the Sierra Madre system that runs along the south front of the San Gabriel Mountains. Its other sides are formed by the nonwater-bearing rocks of the mountains.

This area for the most part lies within the Sierra Madre zone of faulting which traverses the south front of the San Gabriel Mountains. It occupies the re-entrant between two fault salients of the

* Division of Water Resources Bulletin 39, 1932.

PLATE XVI



Spence Airplane Photo

Mouth of San Gabriel Canyon, showing canyon basin area.

mountain-front, and is cut by the series of faults which cross the benches on either side (Plate A). It can be seen from the map that the faults swing northerly, the northern ones cutting the alluvial fill near the northern margin of the area. These faults have only incidental effect upon the ground water, but the more southerly faults strike across the area, and one of these forms an apparently continuous barrier to the movement of ground water across the entire basin. This fault divides the area into an upper and a lower basin. It crosses slightly north of a straight line connecting the south edge of the hills on either side. The lower basin is bounded on the southeast by a fault, marked by a row of low hills in the alluvium, trending northeasterly from Azusa toward the mountain-front. The sharp drop in water levels along the southwest margin indicates a similar obstruction there. However, across the central part of the lower basin the water table appears from the level in well No. C-281 and a dry shaft 216 feet deep one mile to the east, to slope down steeply from the northern margin. Possibly the barrier between San Gabriel Basin and Lower Canyon Basin is not continuous across the central part of San Gabriel cone. At least it is less effective there than on either side.

Character and Depth of the Bedrock Floor.

The alluvial fill in the extreme northern part of Upper Canyon Basin is underlain by Basement Complex. Throughout the remainder of Canyon Basin the floor is probably formed by the tight conglomerates, sandstones, shales and volcanics of the Puente formation, which crop out in the foothills to the east and west of the area. Locally small supplies of water might be obtained from these deposits, but such production would be negligible compared to that of the overlying fill.

The maximum depth of the basins is unknown but their structural position, lying north of the mountain-front faults, and high water table suggest that the northern part is only a few hundred feet deep. The wells are all shallow, being from 100 to 300 feet deep. Well logs indicate that three wells were drilled to bedrock, all on the eastern side of the area. The deepest of these, No. C-325b, one mile west of the eastern edge of the basin, struck bedrock at the depth of 280 feet. The others, nearer the margin, encountered bedrock at shallower depths.

Character of the Water-bearing Series.

The pervious fill in the Canyon Basin area has been derived almost entirely from San Gabriel Canyon and is composed of coarse gravel and boulders, in part practically unweathered and in other places decomposed and tight. Along the northwest side of the basin, Fish Canyon, Van Tassel Canyon and other smaller ravines have contributed sediments locally. Residual clays and clayey gravels are comparatively rare. Well log averages show only eight per cent of clayey material. Boulders several feet in diameter are abundant throughout the deposits and cause difficulty in drilling wells. Ninety-two per cent of the materials reported in well logs is gravel and boulders and eight per cent is clay. Approximately two-thirds of the gravel is unweathered loose gravel, the remainder being classified as tight.

Although the largest boulders at San Gabriel canyon-mouth are considerably larger than those in the vicinity of the south margin of the basin, the gravel deposits of the entire basin are too coarse to vary much in specific yield with different sizes. The minimum value of 13 per cent assigned to very coarse gravel and boulders was used to compute the storage capacity.

Specific Yield and Storage Capacity.

Specific yield contours shown on the map are based on computations for a zone 100 feet thick, from 50 feet above to 50 feet below the water table of January, 1933. The total computed storage capacity of this zone is 29,000 acre feet. Of this, 11,000 acre feet are in Upper Canyon Basin and 18,000 acre feet in Lower Canyon Basin, or 110 acre feet per foot average rise or fall of the water table in Upper Canyon Basin and 180 acre feet per foot average rise or fall in Lower Canyon Basin.

The specific yield varies only slightly over the basin, being estimated to be from 10 to 12 per cent (Plate E) except in the extreme east end of Lower Canyon Basin where it drops to nine per cent. It is thought, therefore, that the computed 110 acre foot capacity per vertical foot of sediments may be considered fairly reliable in the upper basin, even though changes of water level are not uniform within the basin.

Ground Water in the Canyon Basin Area.

Aside from rainfall penetration the ground water in the Canyon Basin area is derived principally from percolation and underflow of San Gabriel River waters, with smaller amounts from Fish and Van Tassel canyons. Spreading of run-off on the basin surface facilitates percolation and increases the average recharge. The effects of spreading are especially important in dry years when available recharge after diversions would be deficient. In wet years the upper basin fills practically to the surface whether water is spread or not.

Water level records * of wells in the upper basin show an annual average maximum water level fluctuation of about 100 feet, or an annual fluctuation of ground water in storage, amounting to approximately 11,000 acre feet. This figure does not represent the total annual recharge but rather represents the accumulated excess of recharge over discharge during the winter and spring months in Upper Canyon Basin. The change of storage from year to year is much less than the seasonal change. It ranges from zero to about 30 per cent of the average maximum fluctuation.

A comparison of well records from Upper and Lower Canyon basins shows that the upper division begins to fill first, and its water table rises to within 40 or 50 feet of the surface before the water table in the lower division begins its sharp rise. In normal and wet years the upper division water table continues to rise until it approaches to within a few feet of the surface, where a balance is reached between inflow and outflow that lasts until the pumping season begins. Apparently the upper 50 feet of alluvial material is not appreciably affected by faulting, and the ground water, restricted at greater depth, flows across the barrier readily from the upper to the lower basin when the water table rises above the critical depth of about 50 feet.

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* Division of Water Resources, Bulletin 39, 1932.

The water table in the lower basin generally reaches a peak one to two months later than in the upper basin, and its peak is 50 to 75 feet lower. Lower Canyon Basin does not fill to the surface even in wet years. Outflow becomes so great when the water table rises, that the maximum inflow into Lower Canyon Basin is balanced by outflow and pumping drafts when its water table is still 50 feet below that of the upper basin.

GLENDORA BASIN

Location and General Description.

Glendora Basin lies beneath an arm of San Gabriel Valley, running southwesterly from Dalton Canyon to the main part of the valley between the San Gabriel Mountains on the north and Glendora Hills on the south. Its west boundary is an arbitrary line running from the west tip of Glendora Hills northwesterly to the foothills of the San Gabriels (Plate E, in pocket). In the southeast corner, Glendora Basin connects with Way Hill Basin through a comparatively shallow neck of alluvial fill about one mile wide. The basin is about two miles wide from north to south and two and one-half miles long with a surface area of 2680 acres.

There are no important sub-surface barriers in the main part of Glendora Basin and no barrier exists between San Gabriel Basin and Glendora Basin; the ground water percolates freely into San Gabriel Basin. Between the eastern part of Glendora Basin and Way Hill Basin there is a sub-surface divide which varies from zero to 200 feet or more in depth. Ground water from Way Hill Basin percolates across this divide and contributes to the supply in Glendora Basin.

Along the north margin of Glendora Basin the Sierra Madre fault zone cuts off an irregular narrow strip of alluvium from the basin to the south (Plate D, Section M-N). The water table stands several hundred feet higher in this area than it does south of the fault zone. Ground water is derived from local run-off from the mountains. The area comprises only a few hundred acres and its storage capacity was not thought large enough to be computed as a basin. Its problems are local and have negligible effect upon Glendora Basin.

Character and Depth of the Bedrock Floor.

The floor of Glendora Basin appears from well logs and distribution of surface outcrops to be Puente sandstone and shale with considerable quantities of volcanic materials (Plate D, Section M-N).

There are no deep wells in the central part of the basin, but several wells near the east and southeast margin have been drilled to bedrock. In this area the basin floor is apparently dropped down along a fault (Plate A) at the eastern edge of the basin, and is deepest in the northern part. Well No. C-404 (Plate E) one mile southwest of Dalton Canyon encountered volcanic material at the depth of 750 feet, or 210 feet above sea level. Toward the southeast corner of the basin the bedrock rises. Wells encounter it there at depths of less than 200 feet (elevation above 700 feet) and along the subsurface divide between Way Hill and Glendora basins it is practically at the surface in places.

Character of the Water-bearing Series.

The alluvial fill of Glendora Basin is made up principally of the composite cone of Big and Little Dalton canyons.

The gravels are typically coarse near the cone apex. Boulders two feet or more in diameter are common. The decrease in size of boulders is rapid, however, toward San Gabriel Basin, and at the southwestern limit of the basin the coarsest material is three to six inches in diameter. However, very little sand is present. The specific yield of unweathered gravel was estimated to be 13 per cent in the northeastern part, and to increase to 20 per cent in the western part. Well logs record 61.5 per cent clay, 0.5 per cent sand, and 38.0 per cent gravel in the alluvial fill. In the southern part of the basin well logs show the clay content to be relatively low, about 45 per cent. It increases toward the northern margin where well logs show an average of a little more than 70 per cent clayey material.

Specific Yield and Storage Capacity.

The specific yields for the zone fifty feet above and 50 feet below the water table of January, 1933, range from nine per cent in the southern part to seven and six per cent along the northern margin (Plate E). Well logs do not indicate an important consistent vertical specific yield variation in this basin, and it is therefore thought that the values shown on the map for the zone 50 feet above and 50 feet below the water table of January, 1933, are fairly representative of the materials above and below that zone.

The computed storage capacity for the 100 foot zone is 19,000 acre feet. The water table does not fluctuate uniformly throughout the basin and since the specific yield is not the same in different parts of the basin, storage changes estimated directly by taking fractional parts of the over-all figure for the 100 foot zone are inaccurate.

Ground Water in Glendora Basin.

The ground water in Glendora Basin, unlike that in Canyon Basin, is not held back by a fault barrier cutting through the alluvium nor by high bedrock. Consequently, the deep central part of the basin drains readily into San Gabriel Basin, forming a water table trough that runs southwest from Dalton Canyon. The ground water drops sharply into this trough from the north side where it is held up by the Sierra Madre fault zone. On the south side the water table slopes more gently northwesterly toward the trough, being influenced by the higher bedrock on that side.

Thus the influence of bedrock and faults along the sides and the lack of a barrier at the west end of the basin produces large variations in the elevation of the water table in different parts of the basin. In January, 1933, the water level in well C-405,* near the mouth of Dalton Canyon, was 515 feet above sea level, and at the same time the water level in wells near the south margin of the basin stood at about 730 feet elevation.

The annual recharge is relatively small, and since the ground water is not impounded behind a barrier but moves slowly through the

* *Op cit.*, p. 201.

basin into San Gabriel Basin, the seasonal fluctuation is relatively small. In well C-405 the fluctuation within a single year varies between 5 and 25 feet, but seldom exceeds 10 feet. In the southern part of the basin where the water table is higher, the fluctuation is somewhat greater.

In years of excessive rainfall and run-off, the water table rises rapidly in the southern and southeastern parts of the basin during the winter and spring months, but drops rapidly during the summer. Recharge of the central and northeastern part is delayed, and the peak is not reached until the spring of the year following that of excessive rainfall and run-off. The reason for this delayed recharge in the deep part of the basin is that the greater part of the stream percolation occurs over the shallow southern part of the basin where the water table rises rapidly. This region of high water table discharges gradually toward the north into the deep part of the basin. In years of subnormal run-off the recharge is slight in the southern part of the basin and is scarcely perceptible in the deeper part. In such years the water table declines almost uninterruptedly. In the extreme southeast part of the basin recharge occurs by subsurface discharge from Way Hill Basin. Well No. C-424 (Plate E) indicates that this recharge continues throughout the summer and fall following heavy run-off, and represents the increased discharge from Way Hill Basin due to building up of the water table.

Although records are not available in the deep portion of Glendora Basin to show the decline of water levels through the 29-year average period since 1904, records for well No. C-405 since the peak year of 1917 show a gradual decline from 650 feet elevation to 520 feet in 1933. This decline was interrupted by rising levels during 1922-1923, 1927-1928, and 1932-1933. The decline curve is flattening.

Scattered records of wells in the south and southeast portion of the basin indicate a probable net decline of less than 25 feet for the period of 1904 to 1933 over a large part of the area.

SAN DIMAS BASIN AREA

Location and General Description.

The San Dimas Basin area lies at the extreme east end of San Gabriel Valley between the San Jose Hills on the south and Glendora Hills and foothills of the San Gabriel Mountains on the north. The east limit is at the subsurface (bedrock) divide near La Verne which separates it from the Pomona Basin area in Upper Santa Ana Valley. The San Dimas Basin area includes: Way Hill, San Dimas and Foothill basins. The surface area is 7850 acres. Way Hill and San Dimas basins join San Gabriel Basin to the west. This boundary is defined as an arbitrary line running southerly from the west tip of Glendora Hills to the San Jose Hills (Plate E, in pocket).

San Dimas Basin area is separated from Glendora Basin in part by a subsurface bedrock divide and in part by Glendora Hills south of Glendora.

The three basins within the area are separated from each other by structural barriers. Foothill Basin is the down-faulted south extension of San Dimas Canyon and tributary drainage from the northeast. It has a surface area of approximately 1150 acres. This down-faulted area lies between Sierra Madre fault zone on the north, and a small fault with upthrow on the south, a short distance north of Cucamonga fault zone.

Character and Depth of the Bedrock Floor.

The alluvial fill of the San Dimas Basin area is underlain by rocks of the Puente formation, except in the northeast corner where the alluvium lies directly on Basement Complex. Volcanic rocks form the greater part of the floor beneath the eastern and southeastern portions of the area. The floor of the western portion is made up principally of sandy and siliceous shale with occasional beds of sandstone and volcanics (Plate D, Section MN). The volcanics in the eastern and southeastern portions are in part fragmental and contain considerable pore space. When these rocks are encountered in wells they yield moderate quantities of ground water. Their distribution, however, is so erratic and local that they have not been considered to be a part of the water-bearing series. The shales which underlie the greater part of the basin are indurated fine-grained deposits which form a relatively "tight" basin floor.

Foothill Basin appears to have a maximum depth of about 200 feet, the deepest part lying approximately beneath the surface wash. To the northeast toward Liveoak Canyon, bedrock underlies the surface at slight depth. Near the southern and eastern margin, bedrock protrudes through the alluvium at several places. Well No. C-464h, near the middle of this area, encountered bedrock at a depth of 110 feet. This basin is separated from the remainder of San Dimas Basin by an up-faulted slice of Puente shales and associated volcanics (Plate A) along the north side of Cucamonga fault, which forms an effective barrier to the movement of ground water.

South of Cucamonga fault, what appears to be the down-faulted extension of the old bedrock floor of San Dimas Canyon forms a deep alluvium-filled trough running southwesterly toward the San Jose Hills (southwest of La Verne), and then westerly between the north margin of these hills and a partially buried east-west ridge one and one-half miles to the north (Plate A). This alluvium-filled trough forms San Dimas Basin.

Bedrock has never been encountered in the deep northern portion of San Dimas Basin, but extensive well development there shows that the bedrock surface is less than 200 feet above sea level, being covered by at least 875 feet of alluvium. Several wells along the southeast edge of the basin show that the bedrock slopes rather steeply northwest from the Pomona Basin area and the San Jose Hills. Southwest of San Dimas the basin has a probable maximum depth of 500 to 600 feet. The great depth of San Dimas Basin near its northern end seems to indicate that if this trough is a down-faulted segment of a former stream canyon, it has suffered some deformation and may now actually be deepest immediately south of Cucamonga fault.

The partially buried Way Hill ridge just north of Bonita Avenue is named for Way Hill, the eastern of the two bedrock hills along it which protrude through the alluvium (Plate A). It slopes rather gently north into Way Hill Basin but drops steeply for several hundred feet along the south side into San Dimas Basin. It may be that the ridge has been uplifted along a fault on its south side.

The third subdivision, Way Hill Basin, is the relatively shallow basin which lies between the Way Hill ridge and the north margin of San Dimas Basin. It extends east to the edge of the northern part of San Dimas Basin and west to San Gabriel Basin (Plate E). Its surface area is approximately 1700 acres.

The floor of Way Hill Basin is high and shelf-like with a broad divide crossing the basin floor in its eastern part. It slopes east into San Dimas Basin from this divide, and gently southwest, gradually merging with San Gabriel Basin. The alluvium is 200 to 300 feet thick in the central part, becoming gradually shallower toward Way Hill on the south.

Way Hill ridge was struck about 100 feet below the surface in well No. C-522a, a short distance west of Way Hill, and at a depth of 185 feet in a well about 1600 feet east of Way Hill.

Way Hill Basin is deepest near its north margin where the bedrock drops abruptly from the north 200 to 300 feet below the surface. The basin may well be faulted down along this margin but the evidence is not clear.

Character of the Water-bearing Series.

The alluvial fill of San Dimas Basin area has originated almost entirely from the crystalline rocks of the San Gabriel Mountains and has been deposited by San Dimas Creek. Contributions from the hills around the basin margin have been insignificant.

The gradient of San Dimas Cone is somewhat lower at its head and more uniform than other similar cones along the mountain-front, and consequently, the gravels are not as coarse at the canyon-mouth as those at the heads of many other cones. Boulders more than one foot in diameter below the canyon-mouth are comparatively rare, and in the southwest part of the basin the coarsest materials are about three to six inches in diameter.

Although gravel in the San Dimas Basin area is not as coarse as that typical of the basins near the mountain-front, well logs show less than one per cent of sand. The gravels are tightest and the clays are most abundant near the basin margins and at depth. In the northeast part of Foothill Basin some wells have penetrated nothing but residual clayey deposits from the surface to bedrock. The average of several well logs in this area showed 98 per cent of clayey material and two per cent of gravel. This material was originally deposited as gravel, but weathering during its intermittent accumulation has altered it to a residual reddish-brown clayey mass. Well logs in the vicinity of San Dimas Wash in Foothill Basin show a little more than 60 per cent clay, less than one per cent sand, and nearly 40 per cent gravel. Well logs along the margins elsewhere in the area also indicate a high percentage of clay, although generally somewhat lower than that in the northeast part of Foothill Basin.

Throughout San Dimas and Way Hill basins the percentage of gravel is comparatively high in the upper 300 or 400 feet of material, and to the depth of 600 feet or more in the Foothill Boulevard area of

San Dimas Basin; but where the alluvium is more than 400 feet thick outside the Foothill Boulevard area, the percentage of gravel is much lower. In Way Hill Basin well log averages give 58.2 per cent clay, 0.5 per cent sand, and 41.3 per cent gravel. Very little of this basin reaches the depth of 400 feet. In San Dimas Basin well log averages give 58.5 per cent clay, 1.1 per cent sand, and 40.4 per cent gravel above the depth of 400 feet, and 88.7 per cent clay, 0.7 per cent sand, and 10.6 per cent gravel outside the Foothill Boulevard area at depths greater than 400 feet. In the Foothill Boulevard area logs show 56.5 per cent clay, 1.0 per cent sand, and 42.5 per cent gravel. Above the depth of 400 feet in this area the percentage of gravel is somewhat higher.

Specific Yield and Storage Capacity.

Due largely to the unequal distribution of clayey materials in San Dimas Basin, specific yield values vary considerably in different parts of the basin and at different depths. The storage capacity computations for the zone 100 feet thick, from 50 feet above the water table of January, 1933, to 50 feet below that water table, gave 32,000 acre feet in San Dimas Basin. Of this storage capacity figure, 53 per cent was above the water table and 47 per cent below. In Way Hill Basin a similar zone was estimated to have 12,000 acre feet capacity. Sixty per cent of this is in the zone above the water table and 40 per cent in the zone below. Since the zone computed was of uniform thickness, bedrock interference is in part responsible for the smaller capacity of the lower zone. No storage capacity was estimated for Foothill Basin.

In San Dimas Basin specific yields are lowest along the east and south margin where values of five and six per cent are indicated. They rise to 10 and 12 per cent in the northern part and along the northwest margin. In Way Hill Basin contours show values ranging from 9 to 13 per cent, the highest values being in the central and southeast part of the basin.

Specific yield values for Foothill Basin, due to its shallow depth, were computed from the surface to bedrock in one zone. Near San Dimas Wash the specific yield is about seven per cent, but toward the northeast it drops to about two per cent. The total storage capacity and annual change of storage in Foothill Basin are so small that they are relatively unimportant factors in the general problems of supply and demand in the San Dimas Basin area.

Ground Water in Foothill Basin.

Foothill Basin is recharged annually in the vicinity of San Dimas Wash by San Dimas Creek, and in the northeast part by the streams that drain into it from the mountain-front east of San Dimas Canyon. Water level records in the northeast part of the basin are incomplete, but it seems probable from the comparatively small amount of run-off and tight character of the basin material, that fluctuations from year to year are small and that there is a gradual decline over a period of dry years and a rise over periods of wet years.

In the vicinity of San Dimas Wash the basin is filled practically to the surface each winter by percolation from San Dimas Creek. The storage capacity of this area is comparatively small and is quickly recharged.

Ground Water in Way Hill Basin.

Direct percolation of run-off from San Dimas Wash is the principal source of ground water in Way Hill Basin. The basin is not enclosed and ground water moves freely west into San Gabriel Basin, and both east and south into San Dimas Basin. The water table is highest in the northeast part of the basin where in January, 1933, it stood at an elevation of about 870 feet. The water table more or less parallels the bedrock but does not rise over bedrock prominences. It diverges from the surface toward the southwest part of the basin.

Way Hill Basin is so situated, with San Dimas Wash running through it, that it receives an immediate annual recharge in normal and wet years. The annual fluctuation varies from about 10 feet in dry years to 60 feet or more in wet years. Well records show a net decline of about 65 feet during the 29-year period since 1905, in the eastern part of the basin. However, this part of the basin has filled to within a few feet of the surface several times during that period. The limited storage capacity, heavy pumping draft and large subsurface outflow, together with a large and direct recharge during wet years, are conditions which produce sharp variations in water levels between wet and dry periods in Way Hill Basin.

Ground Water in San Dimas Basin.

A part of the ground water in San Dimas Basin is derived directly by percolation from San Dimas Wash, but the major portion comes indirectly by underflow from Way Hill Basin. Underflow from Pomona Basin area has been a source in the past.

The water table is considerably lower than in Way Hill Basin. In January, 1933, the water table near Foothill Boulevard in San Dimas Basin stood at about 680 to 700 feet elevation. Toward the southwest the water table sloped down toward San Gabriel Basin, and at the west end of San Dimas Basin stood at an elevation of 400 feet.

Water percolates from San Dimas Wash directly into San Dimas Basin only for a distance of about one-third mile. Consequently, the recharge from this source is small. Its effect is registered quickly, however. Recharge from this percolation produces a fluctuation in years of heavy run-off similar to, but of much less magnitude than that of Way Hill Basin. The indirect recharge is of greater importance, and produces a higher peak the year following heavy run-off. This recharge comes from both Way Hill and Pomona basins.

The record of well No. C-501 (Plate E) for the years 1922 and 1923 shows the typical features of the recharge. In the spring of 1922, following a very wet winter, the water level rose 15 or 20 feet and declined during the summer and fall about 45 feet, then rose about 60 feet, reaching a peak in May, 1923, that was 20 feet higher than the 1922 peak.. The first rise was caused, no doubt, by direct percolation from San Dimas Wash, and the second rise probably was due principally to increased discharge of ground water from Way Hill and Pomona basins.

PUENTE BASIN

Location and General Description.

Puente Basin occupies San Jose Valley southwest of the narrows a few miles from the east end of the valley. The basin is horn-shaped with the large end opening into San Gabriel Basin. The surface area is 10,900 acres.

Structurally Puente Basin is comparatively simple; there are no important barriers to the movement of ground water through the central part of the basin. Lying between the San Jose Hills on the north and the Puente Hills on the south, the basin joins Spadra Basin at its east end and San Gabriel Basin at its west end. An arbitrary line connecting the north ends of the hills on either side of Puente Basin separates it from San Gabriel Basin.

Character and Depth of the Bedrock Floor.

The materials underlying Puente Basin in the western part are Fernando silts, sandy shales and occasional lenses of sandstone and conglomerate. These coarser materials produce water when penetrated by wells, and are in reality, therefore, a part of the basin. Their occurrence is too erratic and limited, however, to be important water producers. The eastern part of the basin is underlain by Puente shales and cemented sandstones.

The basin floor is a canyon or narrow valley filled in its eastern part with alluvium to the depth of 100 to 200 feet. From a point one mile southeast of Puente it deepens from 200 feet to more than 500 feet within one and one-half miles toward San Gabriel Valley, and probably continues to deepen in that direction. The floor of the basin is somewhat irregular, and in the shallower part several bedrock prominences protrude through the alluvium.

Character of the Water-bearing Series.

The alluvium of Puente Basin comes from two sources. In part it is composed of the materials derived locally from the bordering Puente and San Jose Hills. The alluvium along the flanks of the valley is entirely from this source. Through the central part of the valley San Jose Creek has deposited gravels that were brought down from the San Gabriel Mountains by San Antonio Creek.

The alluvium along the flanks of the valley contains a large percentage of clayey material. This is probably due to its very gradual accumulation and to the ease with which the parent rock breaks down. During the recent history of San Jose Valley, San Antonio and San Dimas washes have not discharged into it, and consequently the clayey alluvium derived locally covers the entire valley. Beneath the surface, however, channels of gravel originating largely from the crystalline rocks of the San Gabriels are encountered. These gravels are comparatively clean and are good producers of water. At the lower end of the valley they mingle with similar gravels from San Gabriel River, making a body of good water-bearing materials there.

In spite of the presence of the water-bearing gravels, the average per cent of clayey material is high. Well logs over the entire basin show an average of about 65 per cent clayey material, 5 per cent sand,

and 30 per cent gravel. The clay content is lowest through the central part and highest along the side margins.

Specific Yield and Storage Capacity.

The storage capacity of the 100 foot zone, averaging 50 feet above and 50 feet below the water table of January, 1933, was computed to be 57,000 acre feet. This zone had a uniform thickness of 50 feet below the water table, but, above the water table, varied from 35 and 40 feet near San Gabriel Basin and 30 feet in the eastern part of the basin, to 60 feet along a large part of the southern margin and through the central part in the vicinity of Puente.

Approximately 51 per cent of the computed storage capacity is in the zone above the 1933 water table and 49 per cent below. The specific yields are somewhat higher in the lower part of the zone, but the interference of bedrock more than offsets the higher yields and accounts for the slightly lower capacity of the 50 foot zone lying below the water table.

The distribution of specific yield values as shown on Plate E, for the zone of 100 feet average thickness, varies between three per cent and nine per cent. This high variation is due primarily to the increasing abundance of clayey material toward the side margins of the valley, as described above. Values of seven and eight per cent are common through the central part. The poorest areas along the margins were estimated to have specific yields of three to five per cent.

Ground Water in Puente Basin.

Puente Basin is supplied with ground water principally from two sources: (1) rainfall percolation upon the valley floor and percolation of run-off from the adjacent watershed; and (2) underflow from San Jose Basin. The principal movement of ground water follows the old gravel channels of San Jose Creek through the central part of the valley and through the narrow eastern part of the basin, the water table parallels the bedrock floor. As the basin widens and deepens toward the west the water table flattens and diverges from the bedrock. Through the central part of the basin the water table is generally within 20 feet of the surface, and in wet years rises sufficiently to appear in places along the streambed.

Fluctuations of the water table in Puente Basin are relatively small. The record of well No. C-701,* in the eastern part of the basin, shows an average annual water level fluctuation of about seven to ten feet. The water level recovers rapidly during the rainy season and reaches a peak in the spring. Records of well No. C-700a,† three miles east of Puente, generally show fluctuations of less than five feet a year.

Recharge of Puente Basin takes place during the months immediately following excessive rainfall. Delayed recharge by underflow from San Jose Basin is apparently comparatively small for its effect on the water table is not noticeable from the records of wells in Puente Basin.

* Division of Water Resources Bulletin 39, p. 223, 1932, and Bulletin 39-A, p. 36.
† *Op. cit.*, Bulletin 39, p. 222, and Bulletin 39-A, p. 36.

SAN GABRIEL BASIN

Location and General Description.

San Gabriel Basin occupies the central and western part of San Gabriel Valley. Its surface area is 73,400 acres of 114.7 square miles. The other principal basins of San Gabriel Valley all border on San Gabriel Basin and their underground waste forms a part of the supply in San Gabriel Basin. The underflow out of the basin through Whittier Narrows is relatively constant as there is an excess at all times which rises to the surface and flows through the narrows.

Structurally, San Gabriel Basin is a simple unit without important fault or fold barriers interfering with the movement of ground water through the basin. The north boundary is formed by Raymond fault and faults of the Sierra Madre system. The east boundary is the arbitrary line cutting off the Glendora, Way Hill, and San Dimas basins, and the southeast and southwest boundaries are formed by the hills round that part of the basin. It seems probable that the great depth of the basin is due largely to synclinal folding which has taken place during accumulation of the pervious sediments.

The basin is divisible into three areas on the basis of source of ground water and source and character of the alluvium. These areas are: (1) the western, (2) central, and (3) eastern. The central area occupies a belt about three to five miles wide, running southwesterly from Lower Canyon Basin to the Whittier Narrows. This is the alluvial cone of San Gabriel River. The western area lies between this cone and Raymond fault along the north, and the hills around the west margin of the basin. It occupies the lower portions of the alluvial cones of Arroyo Seco, Eaton and Santa Anita creeks. The eastern area lies between the central area and the west boundary of Glendora, Way Hill, and San Dimas basins and occupies the lower portion of San Dimas and Dalton cones.

Character and Depth of the Bedrock Floor.

The alluvial fill in the southern part of the basin near Whittier Narrows is underlain by the Fernando formation (Plate A), which is a series of soft shales and silts containing large lenses of water bearing gravels interbedded. These gravels interbedded with the silts produce an erratic and somewhat indefinite basin floor in this area. The northwestern and northeastern parts of the basin are underlain by shales and sandstones of the Puente formation with some volcanic material included in the eastern portion (Plate D, sections HI and MN). This formation is probably continuous beneath the alluvium across the northern part of the basin.

The depth of alluvial fill and contour of the bedrock floor are not known except around the west, south and southeast margins. Along the west side of the basin the bedrock floor slopes rather gradually east one to two miles to the depth of about 300 feet and then drops steeply below the bottoms of the deepest water wells. The Rancho oil well (No. C-235d, Plate E) near Garvey Street, two miles north of the hills, indicates a probable thickness of alluvium at that point of 2136 feet, or to the depth of 1892 feet below sea level.

Contours on the base of the alluvium (Plate A) show a probable depth of about 1000 feet in the Whittier Narrows, increasing toward the north. The contours show rather steeply sloping bedrock along the south and southeast margins of the basin. Throughout the central part, well logs show only one point where bedrock was reached. The Vosburg oil well, seven-tenths of a mile south of Arcadia, apparently reached the base of the alluvium at the depth of 1050 feet below sea level (Plate A). From the uniform character of the water table throughout the basin, it does not seem probable that there are any bedrock prominences of importance.

Character of the Water-bearing Series.

The alluvial fill of San Gabriel Basin has been derived almost entirely from the crystalline rocks of the San Gabriel Mountains.

PLATE XVII

Thirty foot gravel bank on upper San Gabriel Cone.

That in the western portion was deposited by the streams west of San Gabriel River. That in the central area was deposited by the river itself, and that in the eastern area was deposited by the streams draining the mountains east of San Gabriel River.

The coarsest gravels in the basin are those of San Gabriel Cone. At the northern margin, boulders two to three feet in diameter are common and beds of sand are absent. The size of particles gradually decreases toward Whittier Narrows until nothing but sand and silt is seen on the surface. However, gravels occur beneath the surface and cobbles up to six inches in diameter are reported from wells drilled near the narrows. On either side of San Gabriel Cone the gravels are much smaller, the largest cobbles ranging from two to about six inches in diameter.

The gravel and clay content varies sharply between the different areas but except in the vicinity of the narrows the sand content is about 10 per cent of the total in each area.

TABLE 7

COMPOSITION OF THE WATER-BEARING SERIES IN DIFFERENT PARTS OF SAN GABRIEL BASIN

Area	Percentages		
	Clay	Sand	Gravel
Western	43.0	9.3	47.7
Central—			
Northeast	11.4	12.9	75.7
Southwest	27.4	27.0	45.6
Eastern	73.9	7.9	18.2

It is clear from Table 7 that the alluvium in the eastern and western areas is much more clayey and consequently poorer in water-bearing properties than that in the central area. An analysis of the ratio of clay to sand and gravel in the different areas shows that the variation in gravel and clay content is independent of the sand content except in the central area. There, the San Gabriel River deposits show an increasing amount of both sand and clay from the head of the cone toward the narrows. Such a gradation appears to be due to the normal deposition of finer materials as the distance from the apex of San Gabriel Cone increases. Evidently the deposits of this central area have remained essentially in the condition that they were originally deposited. Subsequent alteration has been a minor factor. Such is not the case, however, with the deposits of the eastern and western areas. Although the sand content in these areas is low like that over the greater part of the central area, the clay content is high at the expense of the gravel, reaching an average of nearly 74 per cent in the eastern area. This high content of clayey material is due to alteration of gravel and sand by surface weathering, during accumulation of the deposits. Samples from drilled wells show the clayey material to be principally red and yellow gravelly and gritty residual clay derived from coarser deposits.

Specific Yield and Storage Capacity.

The 100 foot zone, averaging 50 feet thick above and 50 feet thick below the water table of January, 1933, for which storage capacity was computed in San Gabriel Basin, is thickest in the area of greatest water table fluctuation, and thinnest where the minimum fluctuation occurs. Starting with zero thickness in the vicinity of Whittier Narrows the zone gradually thickens toward the northwest, north and east margins of the basin to from 120 feet to a little more than 150 feet.

Computed in this manner, the storage capacity of the zone above the January, 1933, water table is 422,000 acre feet and that below, 419,000 acre feet.

The specific yield contours (Plate E) for this zone show the highest values to be in the central area where they range from 11 per cent at the northern margin to 20 per cent between Valley Boulevard and Whittier Narrows. There, maximum yields occur in the area of minimum fluctuation where the water table normally coincides with the surface. The lowest yields are recorded along the southeast margin of the basin where they drop to four and five per cent. Specific yield values between 8 and 12 per cent prevail in the eastern portion of San Gabriel Basin. In the western area specific yield values are slightly higher, varying from 10 to 14 per cent over the greater part.

Ground Water in San Gabriel Basin.

The ground water of San Gabriel Basin originates from three principal sources: (1) direct penetration of rainfall upon the valley floor; (2) percolation of run-off and diverted surface water from San Gabriel River and other streams which enter the valley; and (3) underflow from the tributary basins of San Gabriel Valley into San Gabriel Basin.

The water table is more than 200 feet from the surface around the north and east margins of San Gabriel Basin and about 150 feet from the surface at the west margin, but being flatter than the surface, reaches it above the narrows. The point at which rising water appears in Rio Hondo and San Gabriel River channels varies with the height of the water table.

Normally there is a large annual recharge available to the central area from direct run-off and rainfall percolation which produces a sharp seasonal fluctuation of the water table throughout the highly pervious gravels of the central area. Well No. C-294 * at Baldwin Park fluctuates from five to 30 feet a year. Over a period of wet years there is a cumulative rise and over a period of dry years there is a corresponding cumulative decline. The record of well No. C-294 shows a net rise during the period of excessive rainfall from January, 1905, to January, 1917, of 36 feet, and a decline during the ensuing dry period to January, 1933, of 50 feet. Since there is essentially a free water table in San Gabriel Valley, the area and quantity of rising water fluctuates directly with the rise and fall of the water table.

The direct recharge available to the east and west areas is much smaller. No large streams comparable to San Gabriel River traverse these areas. Consequently, fluctuations are less sharp. These areas are fed principally by underflow from the neighboring basins, and thus there is a lag in recharge and decline. Overdraft in the basins which feed these areas has reduced the inflow and flattened the water table.

* Division of Water Rights Bulletin 5, pp. 542, 543, Bulletin 6, p. 141, and Division of Water Resources Bulletin 39, p. 182, and Bulletin 39-A, p. 28.

CHAPTER VI

UPPER SANTA ANA VALLEY BASINS

Bunker Hill (22)*
Lytle (23)
Devil Canyon (24)
Yucaipa-Beaumont (25)
  Yucaipa Area (25a)
  Beaumont Area (25b)
San Timoteo (26)
  North Area (26a)
  South Area (26b)
Rialto-Colton (21)
  Rialto Area (21a)
  Colton Area (21b)
Riverside (27)
Arlington (28)
Temescal (29)
Spadra (30)
Claremont Heights (17)
Liveoak (18)
Pomona (19)
Cucamonga (20)
Chino (16)

The upper Santa Ana Valley is an irregular shaped oblong structural basin with its long axis in an east-west direction parallel to that of the San Gabriel and San Bernardino mountains. Numerous natural subdivisions exist within the basin. Some are due to bedrock prominences which partially cut off portions of the basin from the remainder and others are due to faults which cut through the alluvium, forming nearly impermeable barriers to the movement of ground water. The basin has a maximum east-west length of a little more than 40 miles and a width of about 18 miles near its western end. The total surface area is a little more than 360,000 acres.

The floor of the basin as well as the borders is very irregular and consists in the main of Basement Complex. Its depth below surface is practically nothing at the margins, more than 1500 feet at Alta Loma, and unknown in large areas. A number of wells (Plate C) have penetrated alluvial fill to depths of more than 1000 feet in different parts of the basin.

Although it is an isolated structural basin, the upper Santa Ana Valley has three openings to the west through which there is limited underflow out of the basin. The most northerly, between San Jose Hills and San Gabriel Mountains, connects San Gabriel Valley with the upper Santa Ana Valley. The surface width of this gap is about two miles. The alluvial fill in it covers a buried bedrock ridge to the depth of about 200 feet. Since the water table is now about 200 feet below the surface in the vincinity of this gap, little or no ground water escapes into San Gabriel Valley except during periods when the water table is higher than at present. There is no surface drainage through the gap.

San Jose Valley west of Pomona forms another outlet for the surface and underground waters from upper Santa Ana Valley into San Gabriel Valley. At its narrowest point the alluvial fill of San Jose valley is about one-half mile wide and there has a depth of a little less than 100 feet. The underflow through this is comparatively

* Numbers in parentheses are index numbers of basins as shown on Plate E in pocket.

small. The surface flow consists of storm run-off in San Jose Creek. There is no rising water.

Santa Ana Canyon west of Prado forms the most important opening through which surplus water from Santa Ana Valley escapes and the only opening through which rising water flows. The width of this canyon is a little more than one-fourth mile at its narrowest point and there the alluvium has a depth of about 80 feet. There is a surface flow through the canyon at all times, and therefore the relatively small amount of underflow is practically constant.

At the east end of the basin, a short distance east of Beaumont, there is a broad alluvium-filled gap connecting the South Coastal Basin through San Gorgonio Pass with the Salton Basin. The ground water in this pass moves southerly from the San Bernardino Mountains, and divides a short distance east of Beaumont, a part moving west into the Beaumont area and the remainder moving easterly toward Banning and the Salton Sea.

SUBDIVISIONS IN UPPER SANTA ANA VALLEY

The San Jacinto fault crosses the valley in a northwest-southeast direction from the mouth of Lytle Creek through San Bernardino and Colton, where it forms the well known "Bunker Hill Dike." This dike is the most effective barrier in the valley and cuts it into two separate basins, each of which has several lesser basins. Above or northeast of the Bunker Hill dike, the principal basins are: Bunker Hill,* Lytle, Devil Canyon, Yucaipa-Beaumont and San Timoteo. Below the dike the principal basins are: Chino, Pomona Basin area, Cucamonga, Rialto-Colton, Riverside, Arlington, Temescal and Spadra. Of these the Chino Basin occupies the large central part of the valley north of Santa Ana River, the other basins being scattered around the margins (Plate E).

SOURCE AND DIRECTION OF MOVEMENT OF GROUND WATER

Percolation of run-off from the adjacent San Gabriel and San Bernardino mountain areas, and percolation of rainfall upon the valley floor are the principal sources of ground water in the upper Santa Ana Valley basins. Above Bunker Hill dike the ground water converges from the northwest, east and southeast toward the artesian area southeast of San Bernardino. Ground water is forced upward from the aquifers in the San Bernardino artesian area and appears at the surface as rising water in Warm Creek and other places, or is lost by evaporation and transpiration at the ground surface.

Below Bunker Hill dike the escaping surface water sinks into the ground, and together with the ground water that escapes through the dike, moves southwesterly into the Rialto-Colton Basin. A part of this ground water is diverted southwesterly into the Riverside Basin where the surplus rises again at Riverside Narrows. The remainder

* The valley area northeast of Bunker Hill dike, from the vicinity of Redlands northwesterly to Cajon Canyon, is commonly referred to as San Bernardino Valley. The term "San Bernardino Basin" has been applied variously to all and to different portions of the area. Therefore, in order to avoid confusion of terms, the three basin names, Lytle, Devil Canyon, and Bunker Hill, are adopted in this bulletin to designate the three basins of the area, as defined in this chapter.

is diverted westerly into Chino Basin where it percolates through the southern part of the basin toward the head of lower Santa Ana Canyon. It converges there with ground water moving southerly from the San Gabriel Mountains and northerly from Temescal Basin. The excess rises in the Santa Ana River bed and flows through the lower canyon as surface water. Ground water moving southerly from San Antonio and Cucamonga canyons forms an artesian area against the Puente Hills south of Chino, and produces rising water in Chino and other creeks which cut into the surface of the artesian area and drain into the Santa Ana River near the head of the lower canyon.

NATURE OF BUNKER HILL DIKE

Bunker Hill dike, contrary to the idea sometimes expressed, is not formed by an up-folded ridge of impervious sediments protruding through the surface at various points along its strike. It is a fault zone running through deep alluvium, and acts as a barrier in two ways. First, by displacement of the strata on opposite sides of the fault, many of the gravel strata are brought opposite clay strata sealing them off. Second, movement on the fault has produced a clay gouge probably varying from a few inches to several feet thick, which acts as a nearly impervious dike running through the alluvium. Deep water wells drilled within short distances of the fault on both sides encounter water gravels at depth, showing clearly that the dike is not a ridge of impervious material.

The surface expression of Bunker Hill dike is a clearly discernible but not very prominent feature running across the alluvial surface. It is marked by a northeast facing escarpment from the mouth of Lytle Creek southeast to Foothill Boulevard. This escarpment has a maximum height of about 75 feet. Toward the southeast, it is marked by several small, long narrow hills and escarpments on the northeast side of the fault, of which Bunker Hill is the most prominent. The scarps have been formed, at least in part, by an uplift of the alluvial surface and the small hills by squeezing up into narrow folds by movement along the fault.

BASINS NORTHEAST OF BUNKER HILL DIKE

Above Bunker Hill dike the area northwest of Crafton Hills, or the valley proper, is locally called San Bernardino Valley. It is subdivided into Lytle, Devil Canyon and Bunker Hill basins (Plate E). The long arm of the valley running up Cajon Canyon and designated "Lower Cajon" on the map is also included but no study was made of this basin. The surface area of the three other basins combined is about 67,000 acres.

The basins of San Bernardino Valley are bounded by the San Jacinto fault (Bunker Hill dike) on the southwest and San Andreas fault on the northeast. The latter separates the deep alluvial fill of the valley from the impervious rocks of the San Bernardino Mountains. The two faults converge toward the northwest and the narrowing basin finally comes to a point in Cajon Canyon, between hills of crystalline rocks which themselves lie between the faults.

Along the southern margin of the valley the Crafton Hills form the boundary in the eastern portion, but west of these hills and their partially buried extension (Plate C), folded water-bearing beds of the San Timoteo formation form the boundary. These folded beds are so different structurally that although they come in direct contact with the overlying alluvial fill of the Bunker Hill Basin, water levels and movements of ground water in the one are not directly related to those in the other.

Character and Depth of the Bedrock Floor.

In the area along the northeast side of the valley, the bedrock floor is very irregular. Several hills protrude through the alluvium and wells near these hills show that their slopes are steep below the alluvial surface. This condition is indicated by bedrock contours on Plate C. Bedrock has been encountered nowhere in the central and southwestern parts of the basin, although wells have been drilled to depths exceeding 1200 feet. Wherever encountered along the northeast side of the basin, bedrock has been found to be hard crystalline rock, similar to that in the protruding hills, and is generally schist. There is a weathered zone several feet to nearly 50 feet thick above the hard unweathered bedrock, however.

Structure Within the San Bernardino Valley.

Although the alluvium of the San Bernardino Valley is in most places unfolded or only slightly deformed, it is cut by several faults, and locally may be sharply folded in the vicinity of these faults. There are at least two lines of northwest-southeast faulting apart from the San Andreas and San Jacinto faults. One of these, the Loma Linda fault (page 63), is approximately parallel to the San Jacinto fault and three-quarters to one mile northeast of it. This fault, although it cuts the surface of the basin only in the extreme southeast part near Loma Linda, and is probably less recently active than San Jacinto, has an important effect upon ground water in the northwest part of the basin. Like the San Jacinto fault, it runs through deep alluvial fill and its effect upon ground water is caused by displacement of the strata and by the impervious nature of the fault zone itself. The effect of this fault upon ground water is evident principally along that segment northwest of Baseline Avenue. In this area there is a maximum difference of nearly 100 feet in the water table on opposite sides of the fault. Farther to the southeast the effect of this fault upon water levels is not evident. The reason for this is probably that such an effect is masked by pressure built up along the less pervious San Jacinto fault.

The Cajon fault, which runs along the southwest margin of Cajon Canyon, enters the basin, and from water levels at two wells near Cajon wash the water table is seen to be about 80 feet higher on the west side of the fault than on the east. This fault appears to run into the Loma Linda fault a short distance north of Highland Avenue, but the wedge included between it and Loma Linda fault is not thought to be of sufficient importance nor conditions in it well enough known to justify study of it as a separate basin.

A sharp break in the elevation of bedrock along the northeast margin of the group of hills north of San Bernardino indicates a third line of faulting, although the alluvial surface is not displaced at any point along this line. This line runs southeasterly from the lower end of Cajon Canyon, but evidence of it is lost southeast of Highland Avenue (Plate C). It is possible that this line of faulting continues through the basin, running along the northeast side of Crafton Hills opposite the mouth of Mill Creek. The trough between this line of supposed faulting and San Andreas fault contains alluvium several hundred feet thick in the area north of San Bernardino and forms the Devil Canyon Basin.

The central part of the valley south of San Bernardino is not cut by any structures that are discernible from the behavior of the ground water. This area is under artesian pressure and this pressure is freely transmitted from one part to another.

Lytle Basin is a strip of alluvium about one mile wide and seven and one-half miles long, lying between San Jacinto fault on the southwest and Loma Linda Fault on the northeast. There are two or more cross structures between these faults that affect ground water in Lytle Basin. One, about a mile south of Highland Avenue, forms the south boundary of the basin and separates it from the artesian area. A second cross structure, about one mile north of Highland Avenue, divides the basin into two hydraulic units, the water table in the northwestern one being more than 200 feet higher than that in the southeastern one. Surface evidence of these cross structures has been destroyed by Lytle Creek, but the water table suggests that they are cross faults or sharp local folds.

Devil Canyon Basin occupies the trough between San Andreas fault and the row of hills about one and one-half miles southwest. The basin is apparently open both at its northwest and southeast ends and through gaps in the hills. However, bedrock is probably too shallow in these gaps to permit underflow through them under ordinary conditions. The southeast boundary of Devil Canyon Basin is an arbitrary east-west line from the tip of the hills to the San Andreas fault.

Bunker Hill Basin occupies the remainder or central part of San Bernardino Valley outside Lower Cajon, Devil Canyon and Lytle Basins. It contains all the present artesian area, although at one time this area extended up into Lytle Basin.

Character of the Water-bearing Series.

The deep alluvial fill of San Bernardino Valley has from all appearances accumulated with little or no interruption except along the margins. The valley receives sediments from streams draining the eastern San Gabriels, the Cajon Pass area, and the San Bernardino Mountains. The concentration of alluvial debris on the east side of San Jacinto fault is probably due in part to subsidence of the block between the San Jacinto and San Andreas faults. The presence of silts and sedimentary clays in the artesian area, together with a general scarcity of weathered yellow, red and brown clays except very near the mountains indicates that the San Bernardino Valley has subsided more than the area west of it, and that deposition within the valley has been relatively continuous. The alluvium is more uniformly pervious than that of the average alluvial basin in this region. The reason for this is that there is less weathered material present. Relatively continuous subsidence of the basin, together with its unusually prolific source of debris, has prevented long and widespread periods of dissection during which reddish-brown and yellow clayey soils develop.

For convenience of description the valley is divided into three areas: one, the northwest area, which is composed of the cones of Lytle and Cajon creeks; a second, the southeast area, composed of the cones of Santa Ana River and Mill Creek; and third, the northeast area, which is the triangular region between the Lytle-Cajon and Santa Ana River cones. The last mentioned area is made up of coalescing cones

PLATE XVIII

Gravel bank on dissected upper Mill Creek Cone, showing four foot cap of Recent alluvium overlying (red) weathered Older alluvium. Note residual clay grading downward into decomposed gravel.

Photo by A. O. Woodford

of the smaller streams draining the steep southwest slopes of the San Bernardino Mountains.

In the Lytle-Cajon area the gravel percentage is highest, being nearly 65 per cent, with clay 30 per cent and sand slightly above five per cent. In the Mill Creek area gravel averages 42 per cent, sand 9.5 per cent and clay 48.5 per cent. In the area between these cones, gravel averages 43.4 per cent, clay 42.6 per cent and sand 14.0 per cent.

The clay in both the northwest area and northeast area has been probably almost entirely developed in place by weathering. This is indicated from well logs and samples from wells drilled during the investigation. However, the somewhat higher clay content in the southeast area is probably due to the presence of considerable sedimentary blue and gray clay and silt in the western part of the area. These sedimentary clays form good caps for artesian aquifers and are in large part responsible for the high artesian pressures that exist in the southwestern part of the valley. The higher sand content in the area between the larger cones (northeast area) is due to the more rapid decrease of coarseness downstream in the smaller cones.

Due to the proximity of high mountains to the northwest and along the northeast margin of the basin, coarse material has been deposited at the heads of all the cones. From Lytle Creek to Mill Creek boulders two to five feet in diameter are common on the various cone-heads and there sand beds are absent. The coarseness decreases very rapidly toward the center of the valley, except on Lytle and Santa Ana River cones, where the decrease of size is much more gradual. On these two cones the coarsest materials are about three to six inches in diameter where the two coalesce in the southwest corner of the basin. Some sand is present there. The alluvial deposits of the smaller streams in the northeast area decrease in coarseness very quickly downstream just as their gradients flatten rapidly (Plate C). Within two miles of the mountains in this area the surface is covered with sand, and gravels encountered in wells seldom have cobbles exceeding three inches in diameter. A considerable portion of the material is sand.

In the alluvial fill of San Bernardino Valley as a whole the sand content is relatively small, averaging less than 10 per cent, and therefore the specific yield of the original gravel is the principal basis upon which yield computations for the various types of materials have been made.

The minimum value of 13 per cent for unweathered coarse gravel and boulders was assigned to the upper portions of Lytle and Cajon cones, the upper portions of Santa Ana and Mill cones, and a very narrow strip adjacent to the southwest margin of the San Bernardino Mountains (Plate F).

The highest specific yield assigned to gravel on Lytle and Santa Ana cones (17 per cent) applies to their meeting point in the southwest corner of the basin. The maximum gravel yield assigned in the area between these large cones was 20 per cent, a short distance northeast of San Bernardino.

Specific Yield and Storage Capacity.

Contours of specific yield for a zone averaging 100 feet thick above and below the water table of January, 1933 (Plate E), show a variation from about 4 per cent to 16 per cent. In Lytle Basin the specific yield varies from 8 to 12 per cent. In Devil Canyon Basin it varies from less than 6 per cent along the mountains to 12 per cent along the southeast boundary. Bunker Hill Basin shows the widest variation, from 4 per cent in the southwest corner outside the artesian area and at the extreme east tip of the basin, to a little more than 16 per cent in the center of the basin, three miles east of San Bernardino. The yields taper off to 6 and 8 per cent along the northeast margin of the valley.

The 100 foot zone for which storage capacity was computed, had a uniform thickness of 100 feet, 50 feet above and 50 feet below the water table of January, 1933, in Lytle and Devil Canyon basins. In Bunker Hill Basin, the area of no storage change, shown on Plate E in the pocket, was excluded from the zone. The zone had a minimum thickness of 10 feet below, and zero above, along the southeast, and 25 feet below, and 10 feet above, along the northwest and northeast margins of the area of no storage change. The thickness of the zone was increased to a maximum of 120 to 140 feet along the northwest, north and northeast margins of the basin, increasing to nearly 200 feet near the mouth of Santa Ana River. In the southern part the zone was increased from 10 or 20 feet to nearly 200 feet at the east end. The thickness above and below the water table was nearly equal except in the vicinity of the area of no storage change.

The storage capacity figure for the 100 foot zone in Lytle Basin is 44,000 acre feet. For Devil Canyon Basin, the figure is 47,000 acre feet. Of this, 55 per cent is above and 45 per cent below the water table. For Bunker Hill Basin (outside the zone of no storage change) the figure is 500,000 acre feet. A little more than 51 per cent of this is above and a little less than 49 per cent, below the water table.

In Lytle and Bunker Hill basins the difference between the upper and lower parts of the zones is not important, but in Devil Canyon Basin the difference is greater. There it is due principally to increased bedrock interference with depth rather than to lower specific yield of the formation.

Ground Water in Lytle Basin.

Percolating flood waters from Lytle and Cajon creeks constitute the principal normal supply of ground water to Lytle Basin. Before wells were drilled in this basin these percolating waters, restricted by the faults bounding the basin, filled it approximately to the surface as far upstream as the junction of Lytle and Cajon creeks.* In 1904 the water table was a little more than 50 feet below the surface in the basin.

The unusual combination of a relatively large water supply, a small basin and an abundance of pervious material has led to intensive well development within a small area and consequent heavy pumping drafts. The result is that the original conditions, as shown by Mendenhall, where the water table was higher within the basin than on either side, has been reversed and now the water table within the narrow basin is 50 to 100 feet lower than that outside the basin (Plate E). The faults which originally restricted the ground water and allowed the basin to fill to the surface, have in a similar manner restricted underflow from adjacent basins into Lytle Basin since the stored waters have been depleted by pumping in Lytle Basin. However, it is probable that a part of the ground water now available to Lytle Basin includes leakage through the slightly permeable fault zones, from the Rialto area on one side and from the Bunker Hill Basin on the other.

Static water levels in Lytle Basin show sharp seasonal fluctuations, generally in the neighborhood of 25 feet, but in extreme cases running to 50 or even 70 feet. In most cases, especially where pumping is heavy, there is a rapid recovery of several feet after the pumps are shut down. Apparently this is a pressure effect, but in recent

* Mendenhall, W. C., *op. cit.*, Plate VII, 1905.

years there has been a continuous recovery during the winter months even in years when there is no recharge from surface flow. It seems probable that this slower recovery is not due so much to pressure effects as it is to recharge of the narrow basin by leakage from the surrounding basins where the water table is higher.

Direct recharge from run-off during wet years occurs rapidly. Its effect is felt within a few weeks in both the upper and lower parts of the basin. As a result of heavy precipitation during the winter of 1921–1922, the water level of well No. D-1188a,* in the upper part of the basin, rose from an elevation of 1368 feet in December, 1921, to 1443 feet in June, 1922, and remained within a few feet of that elevation for the remainder of the year. There was no perceptible recovery the following year. In 1927 the water level in this well recovered from an elevation of 1252 feet in the latter part of 1926, to 1287 feet in April, 1927. The following year there was apparently a slight additional rise to 1299 feet in May, 1928. In the upper part of this basin the effect of pressure is slight and in many wells not evident. The water levels do not recover appreciably at the end of the pumping season, but await recharge from run-off.

Water levels in the lower part of the basin show some pressure effects and also the effects of indirect recharge. The water level of well No. E-5 † showed a recovery from an elevation of 1084 feet in December, 1921, to 1216 feet in May, 1922. The following winter it recovered from 1182 feet elevation in December to 1212 feet elevation in March, nearly as high as the previous peak. From an elevation of 1002 feet in October, 1926, the level rose to 1058 feet on May 1, 1927. The following year it recovered from 1014 feet in October to 1230 feet in February, 1928. Even during periods of several dry years, water levels in the lower part of the basin recover 10 to 15 feet at the end of the pumping season. There is no continuous body of perched water in the area, and it seems probable therefore that the pressure effects become adjusted to the water table within a few weeks, and consequently water levels read after the pumping shut-down recovery and before recharge occurs, probably represent the approximate water table.

The water table in Lytle Basin had receded from within a few feet of the surface in 1904 to a maximum depth of about 300 feet in 1933, but during this period the basin was filled to within a few feet of the surface several times and at these times the underground waste was probably very high. However, with much lower average levels maintained due to the heavy pumping draft, there is no underground waste at present. In fact the balance between inflow and outflow is now in favor of inflow.

Ground Water in Devil Canyon Basin.

Ground water moves southeasterly from Cajon Canyon into Devil Canyon Basin, passing through the basin and around the east tip of the hills along the southwest side, into Bunker Hill Basin.

Stream run-off from Devil Canyon, Twin Creeks and smaller streams percolates into the basin, and together with percolating rain-

* Division of Water Resources Bulletin 39, pp. 436-437, 1932.
† *Op. cit.*, pp. 447–448.

fall, forms a direct and important source of ground water. There is very little underflow into the basin from the streams draining the San Bernardino Mountains, since the San Andreas fault, cutting across the mouths of the canyons, forms an effective barrier to underflow through the gravel channels entering the basin from the mountains.

Devil Canyon Basin is, more strictly speaking, an alluvium-filled trough open at the southeast end. Therefore, the water table has a wide and fairly uniform normal fluctuation throughout the basin, which is controlled by increase and decrease of underflow.

There are very few wells in this basin and pumping drafts have, in the past, probably had little effect upon the water table. The water table normally declines during periods of subnormal precipitation and rises during periods of more than normal precipitation. The longest record available is that of well No. E-10 * near the southeastern end of the basin, which dates back to 1918. The water level in this well shows a gradual decline from an elevation of 1332 feet in 1918 to 1230 feet in January, 1933, with an interruption after the winter of 1921–1922, lasting two years, during which levels rose.

Water levels of wells in this basin do not show pressure effects. There is little or no recovery after the pumping season and before recharge from winter rains reaches the wells. In dry years there is no recovery during the winter and spring months. There appears to be both direct and indirect recharge. In 1922 the water table began to rise within a few weeks after the heavy December, 1921, rains. The recharge continued through the year and reached a higher peak the following year. Probably the delayed recharge came from increased underflow from Cajon Canyon.

Ground Water in Bunker Hill Basin.

Ground water in Bunker Hill Basin originates principally from stream and rainfall percolation, but underflow from Devil Canyon, San Timoteo, and at times from Lytle Basin are important sources of ground water. There is probably also underflow from Lower Cajon Basin across the buried northwest extension of the hills between Devil Canyon and Bunker Hill basins.

Underflow from Santa Ana River, Mill Creek, City Creek and others is very small, due both to the small gravel cross-sections of these creeks where they enter the basin, and to the effective barrier formed by the San Andreas fault between the stream channels and the basin. Since there is very little underflow across the San Andreas fault, the water table drops sharply below the fault and has a comparatively gentle slope toward the central part of the basin. The slope is steep from Mill Creek to the Santa Ana River, however, on account of high bedrock in that area. The slope from Devil Canyon and lower Cajon basins is steeper than that from the eastern part of the basin.

Bunker Hill Basin is divided into an artesian pressure area and an intake area. In the nonpressure area the water table fluctuates freely according to the increase or decrease of underflow, and these changes represent changes of storage. Pumping drawdowns have only local effect, and after the pumping season ends there is no appreciable recovery until actual recharge from rainfall or run-off occurs. Within

* *Op. cit.*, Bulletin 39, p. 451, and Bulletin 39-A, p. 70.

the artesian pressure area, however, water level fluctuations are due to changes of pressure within the aquifers. Such changes are due both to pumping or artesian flow effects, and to changes in the height of the water table in the adjacent non-pressure area, which forms the head for artesian pressure.

During the winter months when pumping is at a minimum, water table changes outside the pressure area are more or less reflected by the static pressure in the artesian area, and a decline of the water table over a period of years is reflected by a decline of pressure also. However, the artesian pressure area is saturated to the surface and therefore no changes of storage occur within it. The artesian area has shrunk with the decline of the water table and in this manner the area in which storage change occurs has increased. Outside the present artesian area wells show some pressure effects, but these are principally the deeper ones, and shallow well level changes there measure changes of storage.

The Pressure Area. The pressure area has been produced as a result of movements on San Jacinto fault (Bunker Hill dike), which has formed a nearly impervious barrier in the alluvium along the southwest side of the area. Northeast of Bunker Hill dike the basin has apparently been repeatedly depressed, producing swampy flood plain topography. Consequently, depositional blue and gray clays and silts have accumulated in blanket-like deposits, with gravel and sand beds between, forming effective caps under which artesian pressure has accumulated. In this respect the Bunker Hill pressure area is similar to that of the Coastal Plain. Some of the deeper impervious strata extend farther outward toward the sources than do most of the shallower impervious beds. Furthermore, the different aquifers are not connected directly, and consequently wells drilled to different depths have different water levels. Commonly deeper wells show the greatest heads. In the southwestern part of the basin several deep wells encounter hot water, probably of deep seated origin, that apparently comes up along faults and enters the water-bearing strata where it is held down by the ground water pressure of the artesian basin.

The Bunker Hill artesian pressure area is not merely the lower end of the usual type of alluvial ground water basin where the excess water rises and flows in surface channels, as it does above Riverside Narrows, Lower Santa Ana Canyon, Whittier Narrows and other places. The development of comparatively high artesian pressures is due to the peculiar local structural conditions described above.

Static pressure in the artesian area, measured during the winter when production is at a minimum, has followed quite closely the trend of water levels in the non-pressure area. The pressure, as shown by Mendenhall, in 1904 had declined considerably from its so-called original limit, this decline being represented by a shrinkage of the artesian area.

The record of well No. E-109,* extending from 1900 to the present, is the best available in the basin and is probably representative of conditions outside the pressure area in the eastern part of the basin. The water level in this well has an average annual fluctuation of about 10 feet, the maximum fluctuation in wet years is 15 to 20 feet, and the

* *Op. cit.*, Bulletin 39, pp. 514-515, and Bulletin 39-A, p. 77.

minimum about 5 feet in dry years. There is generally not an important water level recovery after the pumping season, until recharge from winter rains begins, although in some years there appears to have been several feet recovery before actual recharge could have affected the levels.

At the end of 1904, the water level of this well reached a low of 1110 feet elevation, after which it gradually rose to within a few feet of the ground surface (1152 feet elevation) in 1916.

During the several wet years following 1904, and again during 1915, 1916 and 1922, the artesian pressure rose and the area of artesian flow increased to the neighborhood of the line shown by Mendenhall.* as "approximate original artesian limit." Well No. E-109 is practically on this line and on the south bank of the Santa Ana River. The water level in this well, as stated above, has been within five feet of the surface several times since 1904.

It seems doubtful whether artesian pressure could ever be built up beyond the line of original artesian limit shown by Mendenhall, for the necessary silt and flood plain clay beds have practically disappeared before this outer limit of the artesian area is reached.

YUCAIPA-BEAUMONT AND SAN TIMOTEO BASIN AREA

Location and General Description.

In the area southeast of Bunker Hill Basin toward Beaumont, there is an elevated alluvial plateau deeply dissected in its western portion by San Timoteo Canyon and its tributaries. The plateau remnants in the Beaumont and Yucaipa areas lie at elevations of 1000 to 1500 feet above San Bernardino Valley in the Redlands-San Bernardino area. The largest remnant of this surface slopes rather gently southwesterly and southerly from the San Bernardino Mountains and is known generally as the Beaumont Plains. The surface is covered by deeply weathered reddish-brown soil, all traces of the original gravel having disappeared. Steep-sided, flat-bottomed ravines cut across the plains, becoming deeper toward San Timoteo Creek, which itself, from a depth of only 25 feet below the plain near Beaumont, gradually becomes deeper toward the northwest being finally about 1000 feet lower than the plain, where it empties into San Bernardino Valley a short distance west of Redlands.

This plateau area lies between the San Bernardino Mountains and its outliers, along the northeast, and the San Jacinto fault and the badland hills south and west of Beaumont. To the east the basin is connected through San Gorgonio Pass with the Colorado desert region. The north boundary is formed in part by the Crafton Hills and their buried bedrock extension to the west, and partly by the contact between the folded beds of San Timoteo Basin and the alluvium of Bunker Hill Basin.

Two basins have been designated in the area. They are: (1) San Timoteo, and (2) Yucaipa-Beaumont. These are not two separate basins according to the usual definition of a basin, but are different depth zones within the same basin. However, since the areas producing

* Mendenhall, W. C., U. S. Geological Survey Water-Supply Paper 142, Pl. VII, 1905.

water from the different zones are not superimposed, but lie adjacent with but little overlap, they are considered to be different basins.

Structure.*

The Yucaipa-Beaumont and San Timoteo basins lie in what appears to be a long, gently folded syncline whose axis runs northwest and southeast. The southwest limb of this structure is well exposed in San Timoteo Canyon which parallels its strike. Here the San Timoteo beds outcrop along both sides of the canyon. They dip at gentle to moderate angles toward the northeast and pass beneath the Quaternary alluvium of the Yucaipa-Beaumont Plains northeast of the canyon. The strata dip more gently on the northeast side of the canyon, and are practically horizontal where they disappear beneath the Quaternary alluvium. The structure of the San Timoteo beds is concealed along the northeast side of the basin, and it is therefore not clear whether the basin is a true syncline, or whether the tilted beds along the southwest side merely flatten toward the northeast and are faulted down against the Basement Complex. The San Timoteo beds overlap the westward projections of the Basement Complex both north and south of the Yucaipa area, as can be seen on Plate C. At other points along the northeast side of the basin the San Timoteo beds probably are faulted down against the Basement Complex.

Character and Depth of the Bedrock Floor.

The Water-bearing series consists of two alluvial formations. The older, the San Timoteo beds, contains in its upper part a folded alluvial series 700 to 1500 feet or more thick, of probable Lower Pleistocene age, overlying fine gray sands, silts and clays. The younger formation is the relatively undeformed Quaternary alluvium which covers the Beaumont and Yucaipa Plains, lying unconformably on the San Timoteo beds.

Several wildcat oil wells have been drilled in the basin and these give some clue as to its nature and depth. The deepest of these wells, located about midway between Liveoak and San Timoteo creeks, was drilled to the depth of 5000 feet without encountering Basement Complex. Coarse alluvial deposits similar to those exposed along San Timoteo Canyon were penetrated to the depth of 695 feet, and below that point the log records sandstone and shale.

In the hills a short distance south of Beaumont, two wildcat oil wells have been drilled to Basement Complex, a depth of a little more than 1200 feet. Cores from below 1000 feet in one of these showed what appeared to be light gray, thinly bedded marine shales and sands. This evidence and the presence of thick sandstone and shale sections reported from beneath the San Timoteo beds in well logs of other wildcat wells in the region, suggests that the ocean bottom of the Tertiary Salton Basin extended northwesterly into the Yucaipa-Beaumont area. Tertiary marine fossils occur along the mountain front about 15 miles northeast of Beaumont.

In the vicinity of San Jacinto fault, along the southwest side of the basin, where the lower part of the alluvial series is exposed, it is inter-

* The geologic structure of this area was worked out by C. W. Johnson of the Division staff.

bedded with light gray sands, silts and clays. Some of the clays are weathered reddish material, but this lower part of the section is as a whole much finer, and contains only occasional lenses of gravel. At several points along the fault near the northwest margin of the basin, lake beds containing small fresh water fossils are exposed beneath the San Timoteo beds. These lake beds form the floor of at least a part of the basin and may extend beneath the greater part of it. However, the lower few hundred feet of the San Timoteo beds are themselves probably practically nonwater-bearing. The total thickness of the San Timoteo beds is estimated to be between 1500 and 2000 feet, but logs of deep wells near the central part of the basin penetrated water-bearing gravels to depths of only 700 to 1000 feet.

The Quaternary alluvium that overlies the San Timoteo beds in the central and northeastern part of the basin is probably thickest near Yucaipa and north of Beaumont where the cones are high. The Quaternary alluvium thins in a wedge-like manner toward the southwest and disappears in the central part of the basin, except for insignificant amounts of Recent alluvium in the stream channels (Plate C). Probably these alluvial deposits do not exceed a few hundred feet in thickness anywhere and they lie above the water table in most parts of the basin.

The Quaternary alluvium and San Timoteo beds are so similar in their physical characteristics that they could not be distinguished from each other in well logs.

Character of the Water-bearing Series.

The Quaternary alluvium, as can be seen from the map, is made up of debris from the high crystalline area along the northeast margin of the basin (Plate C), but the source of the San Timoteo beds is more obscure. These beds, like the overlying alluvium, are composed of crystalline debris, principally granites, pegmatites, schists and gneisses. There are also some pebbles and cobbles of volcanic material present.

The unaltered beds are principally gravels and sandy gravels. The coarsest gravels contain few cobbles more than six inches in diameter, and more commonly cobbles of two to four inches in diameter are the largest found in the gravel beds. In the upper part of the section there is comparatively little true sand or depositional silt or clay. The high percentage of clay present in this section is due to weathering and soil formation during accumulation of the deposits.

Although the upper part of the section as a whole is distinctly coarser than the exposed part of the lower portion, differences in coarseness of the upper beds in different parts of the basin are slight and the trend is uncertain within the areas where the gravels are exposed.

Gravels in the Quaternary alluvium near the heads of the cones along the northeast side of the basin are much coarser than those exposed in the San Timoteo beds. Sub-angular boulders more than 12 inches in diameter are not uncommon there. The steeply sloping cones flatten rapidly toward the southwest and the gravels become correspondingly smaller. Pebbly gravels and coarse sands predominate in the washes of the southwest part of the basin.

The clay and gravel content in different parts of the area, as shown by well log averages, is remarkably uniform. In the western part of the Yucaipa area, where the wells penetrate principally Quaternary alluvium, there is an average of 77.2 per cent clay, 0.3 per cent sand, and 22.5 per cent gravel. In the southeastern part of the same area, the wells penetrate both Quaternary alluvium and San Timoteo beds. Here well logs show 53.6 per cent clay, 0.7 per cent sand, and 45.7 per cent gravel. In the Beaumont area, there is 70.0 per cent clay, 0.7 per cent sand and 29.3 per cent gravel. These well logs probably represent both Quaternary alluvium and San Timoteo beds. Well logs in the San Timoteo area give an average of 75.0 per cent clay, 3.2 per cent sand and 21.8 per cent gravel. These wells are drilled almost entirely in San Timoteo beds.

It can be seen from this distribution of clay and gravel, that with the exception of the southeastern part of the Yucaipa area the deposits are very similar, having roughly one-fourth gravel and three-fourths clayey material. The sand content is generally negligible. Why the water-bearing deposits contain more gravel in the southeastern part of the Yucaipa area than elsewhere in the basin is not clear. Probably the original deposits have suffered less weathering there than elsewhere.

The specific yield of unweathered gravel in the Quaternary alluvium was estimated on the basis of gravel coarseness to vary from a minimum of 13 per cent near the cone heads to a maximum of 18 per cent in San Timoteo wash (Plate F).

The yield of unweathered gravel in the San Timoteo beds was estimated on the same basis to be 16 per cent. Throughout the central part of the basin the specific yield of gravels in both the Quaternary alluvium and the San Timoteo beds is 16 per cent and since the Quaternary alluvium in the southwest part of the basin is negligible, the highest gravel yields used in computing specific yield values for the basin was 16 per cent. Well log groups located toward the northeast side of the basin where the Quaternary alluvium thickens were given correspondingly lower gravel yield values.

Specific Yield and Storage Capacity.

Owing to the scarcity of well logs and uncertain relationship between the Quaternary alluvium and the underlying San Timoteo beds, the logs were averaged together from the surface to the bottoms of the wells, or to the base of the water-bearing beds in deep wells, giving one computed specific yield value for all depths. Consequently, the specific yield contours shown on Plate E, for a zone 100 feet thick, above and below the water table of January, 1933, are applicable also to other depths in this basin.

The computed specific yield, as shown on Plate E, varies from less than four per cent northeast of Yucaipa and south of Beaumont, to a maximum of about 10 per cent in the southeastern part of the Yucaipa area. In the San Timoteo area the average yield is six per cent over the greater part of the basin but rises to nine per cent toward the northern edge.

The estimated storage capacity of the 100 foot zone in the Yucaipa area is 99,000 acre feet and in the Beaumont area 60,000 acre feet.

The two areas were separated by an arbitrary line extended from the west tip of the bedrock hills separating the eastern part of the two areas (Plate E) due west to the edge of San Timoteo Basin.

The storage capacity of a zone 50 feet thick below the water table of January, 1933, in the north area of San Timoteo Basin is estimated to be 48,000 acre feet. In the deeper side ravines and along San Timoteo Canyon the water table is at or near the surface, and it is thought that the basin is practically full at present. Therefore, the storage capacity above the water table was not estimated in this basin. Due to lack of data, no storage capacity was computed for a similar zone in the south area of San Timoteo Basin.

Ground Water in Yucaipa-Beaumont Basin.

Yucaipa-Beaumont Basin receives percolating flood waters from the comparatively small watershed adjacent to it northeast of the San Andreas fault (Plate C), and from the local hills along the irregular northeast edge of the basin. Percolation of rainfall upon the valley floor is probably the only other important source of ground water in the area. The area of the basin is unusually large (27,020 acres) compared to its tributary watershed.

The ground water moves through Yucaipa-Beaumont Basin in a southwesterly and westerly direction. Underflow from Little San Gorgonio Creek feeds the Beaumont area, and underflow from the vicinity of the San Andreas fault northeast of Yucaipa feeds the Yucaipa area.

In the Yucaipa area the water table slopes steeply from the San Andreas fault through the narrows to Yucaipa and flattens in the broad part of the basin southwest of Yucaipa. It approaches and in places reaches the surface in Liveoak Creek and other ravines to the north, causing the water table slope to steepen sharply along a north-south line through the middle of Yucaipa area. It flattens again in the northwest corner of the basin and converges with the surface and intersects it near Liveoak Creek (Plate E). The western edge of the basin lies approximately along the line of emergence of the San Timoteo beds from beneath the alluvium. These beds dipping northeasterly form barriers to the ground water which moves in the opposite direction, and cause it to rise to the surface at the low point of the western rim of the basin in Yucaipa Valley.

In the Beaumont area conditions are similar to those in the Yucaipa area. The water table drops steeply from the mouth of Little San Gorgonio Canyon into the main part of the basin and gradually flattens toward the south. The ground water in this area divides, so that a part of the underflow moves easterly out of the basin through San Gorgonio Pass, and the remainder swings westerly, rising to the surface as springs and in wells along San Timoteo Canyon at the extreme western edge of the basin.

In the northeastern part of the Beaumont area, the underflow from Little San Gorgonio Canyon enters the deep part of the basin at a high level, and a part of the ground water is held up by tight material, forming perched water which extends south and west for some distance before it drains to the lower level. Consequently, water levels in different wells in this region are erratic and difficult to interpret. Percolation from rainfall and irrigation add to the perched water.

Water level records in most parts of this basin show relatively small seasonal fluctuations and a rather steady decline over the last 15 years, without significant recovery during the following wet years. Water levels in nearly all wells recover a few feet in the fall after the pumping season, indicating that the ground water is under some pressure. This condition is due to the high percentage of clay throughout the basin, which, though it probably does not confine the ground water to certain gravel beds, does restrict its movement from one bed to another. The pressure effect is comparatively slight, however, and water levels probably become adjusted to the water table level within a month or two after pumping ceases.

The annual fluctuation of water levels is usually about 5 to 10 feet per year. Well No. E-132,* in the western part of the Yucaipa area, shows a water level decline of approximately 60 feet from January, 1920, to the latter part of 1932. The decline has been less in most parts of the area. In the Beaumont area conditions are similar. The records in Bulletins 39 and 39-A show for Well No. E-233 in the northwestern part of the area a water level decline from the latter part of 1921, to a similar date in 1932 of about 50 feet; for Well No. E-240 (Plate E) during a similar period a decline of only 12 feet; and for Well No. E-234, at the western edge of the basin where the water table approaches and in places reaches the surface, a decline of only three feet since the latter part of 1921.

The gradual but steady water table decline over the greater part of Yucaipa-Beaumont Basin, together with the failure of recharge from wet winters to show a pronounced effect on it, results from the comparatively large storage capacity and small supply available to the basin. As the water table is lowered, the natural waste from rising water and underflow along the western margin of the basin diminishes.

Ground Water in San Timoteo Basin.

Underflow from Yucaipa-Beaumont Basin, and rainfall percolation are the principal sources of the ground water in San Timoteo Basin. Percolation of run-off locally adds to the ground water supply, but throughout Liveoak Canyon and a large part of San Timoteo Canyon ground water lies too near the surface to permit any material percolation. In the side ravines, especially those draining into San Timoteo Canyon from the southwest, probably a considerable part of the run-off percolates into the basin.

As shown on Plate E, the ground water moves westerly from Yucaipa-Beaumont Basin to San Timoteo Canyon, and thence northwesterly along the canyon to Bunker Hill Basin.

Although rising water appears at the surface in only a few places in the basin along the principal streams, it is near enough the surface to suffer transpiration and evaporation losses. Consequently it may be said that the topography controls the shape of the water table in this basin. The underflow from Yucaipa-Beaumont Basin, rising along the tilted San Timoteo beds, appears at the surface where these beds crop out in Liveoak Canyon. The water which thus escapes from the

* Division of Water Resources Bulletin 39, page 535, and Bulletin 39-A, page 80.

San Timoteo beds is carried as underflow through the recent fill of Liveoak and San Timoteo canyons, and where there is an excess it appears as rising water in the stream beds. If it were not for pumping drafts and transpiration losses in these canyons the streams would flow throughout most of their courses. From a comparison of their topography with ground water contours in San Timoteo Basin, it can be seen that the relatively steep descent of the water table from Yucaipa-Beaumont Basin westerly corresponds to the break in topography from the Yucaipa and Beaumont Plains to the level of San Timoteo Creek.

In San Timoteo Canyon there may be a depth of 50 to 100 feet of Recent alluvial fill through which the ground water percolates toward Bunker Hill Basin, but the ground water in this fill is only incidental, being fed by that of San Timoteo beds through which it runs. However, transpiration losses and pumping drafts along the canyon produce a local fluctuation of the water table in the recent fill which probably has no significance except in the immediate vicinity of the canyon. The storage changes in this narrow strip are thought to be negligible and therefore the storage capacity was not considered separately.

The seasonal fluctuation of water levels along the canyon is ordinarily within the range of 2 to 10 feet and appears to be smaller in wells nearer the canyon bottom.

Water levels along San Timoteo Canyon show fluctuations of several feet, over longer periods. The records in Bulletins 39 and 39-A show that in Well No. E-117 the level declined about seven feet from 1921 to 1932; in well No. E-225, the level from December, 1926, to January, 1933, showed a net drop of only one foot. The best record available for the San Timoteo Canyon area is E-107b. This well is outside what is considered to be San Timoteo Basin but its ground water is the underflow from the basin and its water level fluctuations are probably similar to those in the canyon. The record of this well showed the depth to water in January, 1905, to be 81 feet. It reached a peak during 1918 and in the early part of 1919. The depth to water in January, 1919, was 38.8 feet. Apparently this peak was due to the wet period which ended in 1916, indicating a lag of two or three years. There was a similar peak in 1923, following the wet winter of 1921-1922, the depth to water in January, 1923, being 37.3 feet. There was no perceptible rise following the wet winter of 1926-1927, and since that time the water table has declined more rapidly, reaching the depth of about 85 feet in January, 1933.

It would seem from these records that there is a considerable lag in the response of the water table levels in the canyon to wet and dry periods. Evidently, therefore, the water table in the recent alluvium is influenced by the rise and fall of that in the San Timoteo beds more than by direct recharge from run-off.

In Liveoak Canyon there is very little fluctuation of water levels over a period of years. This is accounted for by the presence at all times of rising water at places in the canyon.

It seems clear from the foregoing data that there is a slight surplus of ground water supply in the San Timoteo beds at all times, which discharges as underflow in the Recent fill of Liveoak and San Timoteo canyons, and at places as springs where the beds crop out above these canyon levels. The rising water in Liveoak Canyon and at times in San Timoteo Canyon is surplus above the capacity of the Recent fill.

RIALTO-COLTON BASIN

Location and General Description.

Rialto-Colton Basin occupies the area immediately southwest of the Bunker Hill dike. Its southwest boundary is formed by another fault which diverges from the San Jacinto fault toward the northwest. The basin has a width of only one mile at the edge of the hills southeast of Colton, but at its northwest end, along the San Gabriel Mountain-front, its width is about five miles. The area is approximately 35 square miles or 22,630 acres. The surface is covered entirely by Recent alluvium of Lytle Cone and Santa Ana River. It is practically undissected except near Santa Ana River where the river has cut below the surface of Lytle Cone about 40 feet. The basin occupies almost the entire upper portion of Lytle Cone, narrowing southeasterly down the cone to Santa Ana River.

There are no clearly defined structural subdivisions of importance within the basin except at the mouth of Lytle Creek Canyon, but it has been separated into two areas on the basis of its outflow. The northwestern division, Rialto area, contributes underflow to Chino Basin, and the southeastern portion, Colton area, contributes to Riverside Basin. Riverside Avenue, running through Rialto, forms a convenient approximate boundary for the two areas.

Character and Depth of the Bedrock Floor.

The depth of Rialto-Colton Basin is unknown as no wells within the basin have been drilled to bedrock. A well 754 feet deep in the northwest corner failed to reach bedrock. Another, 890 feet deep, about one mile northwest of Rialto, ended in alluvial fill. There are several other wells 300 to 800 feet deep in different parts of the basin that penetrate only water-bearing deposits.

Since bedrock has not been encountered within the basin, it is not known how far northwesterly beneath the water-bearing beds the silts and shales that underlie the water-bearing deposits of San Timoteo Basin extend.

Character of the Water-bearing Series.

Rialto-Colton Basin is filled with alluvial material, principally the deposits of Lytle Creek. Cajon Creek material is present along the eastern margin, and in the southwest portion near Colton, the deposits are probably mostly from Santa Ana River. With the exception of a relatively insignificant amount of sandstone pebbles and cobbles from Cajon Creek and Santa Ana River, the alluvial material is composed of crystalline Basement Complex rocks.

The coarsest material occurs at the head of Lytle Cone, where boulders several feet in diameter are common. Sand beds are absent from this area. The deposits become finer toward the southeast where the coarsest gravels contain few cobbles more than 4 inches in diameter. In this part of the basin the surface is almost entirely covered by sand, very little gravel being exposed even in the washes.

Well log averages show the clay content in the Rialto area to be 38.5 per cent, and in the Colton area to be 39.3 per cent. These percentages are comparatively low and uniform, which might be taken to indicate that deposition has been fairly continuous on Lytle Cone. The logs show only 4.3 per cent of the material to be sand in the Rialto area, and practically all of this is in the southeast portion. The sand content increases to an average of 16.5 per cent in the Colton area, and since the amount of clay present is nearly uniform, gravel which is 57.2 per cent in the Rialto area decreases to 44.3 per cent in the Colton area. Since there is practically no sand present in most of the Rialto area, the amount of clay deposited there is probably negligible, and the clayey material present, amounting to nearly 40 per cent of the deposits, is probably due to weathering of the deposits and soil formation during their accumulation. The sharp increase in sand content, however, toward the southeast, suggests that clays also have been deposited there and evidently these depositional clays have just about offset the less effective formation of clayey material by weathering on the lower slopes of the cone.

The relatively high percentage of gravel and sand in the basin is favorable to high unit storage capacity. The low specific yield of the very coarse gravels in the Rialto area, however, has resulted in a much lower unit storage capacity there than in the Colton area.

For storage capacity computations the minimum specific yield value of 13 per cent was assigned to unweathered gravel over the greater part of Rialto area (Plate F), with a maximum of about 15 per cent at the southern end. In the Colton area the specific yield value of unweathered gravel was increased to a maximum of about 18 per cent in the vicinity of Santa Ana River.

Specific Yield and Storage Capacity.

The specific yield contours based upon storage capacity computations for a zone 100 feet thick, above and below the water table of January, 1933, show a variation from 6 per cent at the northwest margin of the Rialto area to 14 and 16 per cent in the central part of the Colton area (Plate E). It is interesting to note that the highest specific yields occur in the Colton area about two miles northwest of the Santa Ana River. Probably the lowest part of the valley, through which Santa Ana River flowed, was at this point during accumulation of the deposits in the zone for which capacity was computed, and has been pushed south more recently by the growing Lytle Cone.

In the Rialto area the zone estimated had a uniform thickness of 100 feet, but in the Colton area it varied from a minimum of 30 or 40 feet in the vicinity of the Santa Ana River to about 150 feet at the north end, but averaged 100 feet. The storage capacity estimated for the Rialto area (west of Riverside Avenue), is 120,000 acre feet or 1200 acre feet per foot average rise or fall of the water table. Half of this capacity lies above the water table, and half below. In Colton area (east of Riverside Avenue) the estimated storage capacity is 93,000 acre feet. The storage capacity for the 50 foot zone above the water table in the Colton area contains 54 per cent of the total, and that for the 50 foot zone below contains 46 per cent. There is no bedrock interference in this area, and therefore the discrepancy between the two portions of the zone is due to smaller specific yield values in the lower portion.

Ground Water in Rialto-Colton Basin.

Percolation of run-off from Lytle Wash where it runs through the northeast corner of the basin, and percolation of rainfall upon the cone are the principal direct sources of ground water in the Rialto area. There is also an indirect recharge from underflow out of Lytle Canyon. Before heavy pumping in Lytle Basin depleted the ground water in storage there, restricted underflow took place through Bunker Hill dike into Rialto area.

In the Colton area direct recharge occurs from rainfall penetration and to some extent from run-off in Santa Ana River and the lower part of Lytle Creek. However, the principal source of ground water is underflow through Bunker Hill dike.

The ground water moves southerly through the Rialto area from Lytle Wash, a part of it percolating through the fault which forms the southwest boundary of the basin into Chino Basin, and another part moves southeasterly into the Colton area. Under present conditions there probably is also a small loss of ground water from the Rialto area by underflow through the Bunker Hill dike into Lytle Basin.

Movement of ground water through the Colton area is southwesterly, the outflow passing into Riverside Basin.

In January, 1933, the water table stood a little above 1800 feet elevation in the upper part of the Rialto area near the mouth of Lytle Canyon. It sloped steeply south from this part of the basin to about 1300 feet elevation and then more gently, to a little less than 1000 feet in the southern part of the area. High bedrock on the north side of what is probably the easterly extension beneath the Lytle Cone alluvium of the Sierra Madre fault zone (Plate C) is probably responsible for the area of high water table in the vicinity of the mouth of Lytle Creek. Faulting may also be responsible for the extension of the high water table southeasterly between Riverside Drive and Bunker Hill dike (Plate E).

Water levels in the northeast part of the basin show sharp seasonal fluctuations and rapid direct recharge from run-off in Lytle Wash. The water level record for well No. D-1181c shows annual fluctuations of 75 to nearly 100 feet * in years of heavy run-off, and somewhat less in dry years. Recharge occurs during the winter and spring months. The net decline from December, 1914, to the early part of 1933 was only about 20 feet.

Water level records throughout other parts of the area are too scattered to indicate clearly the nature of depletion and recharge there. Fluctuations are comparatively slight in that part of the Rialto area where the water table is low.

In the Colton area the water table approaches the surface toward Santa Ana River, and in January, 1933, was at a depth of 20 to 30 feet below the river bed. Fluctuations are comparatively small in this part of the basin, but increase toward the Rialto area where seasonal fluctuations vary from 10 to about 40 feet. Although the water gravels yield

* Division of Water Resources Bulletin 39, p. 434, and Bulletin 39-A, p. 68.

good supplies freely in this area, development has been very limited, and consequently, water level records are meager.

RIVERSIDE BASIN AREA

Location and General Description.

The Riverside basin area lies southwest of the Colton area, occupying the alluvial valley in which Riverside and Arlington are situated. It is separated from the main part of Upper Santa Ana Valley by a row of bedrock hills along its northwest margin, but has an alluvial connection with Temescal Basin through the gap in the hills southwest of Arlington. This is called Arlington Gap. A ground water divide in the alluvium between Riverside and Arlington separates the area into two basins. Arlington Basin lies southwest and Riverside Basin northeast of the divide (Plate E). The surface area of Riverside Basin is a little more than 50 square miles or 32,160 acres, and that of Arlington Basin about 14,180 acres.

The major part of the area is covered by an old alluvial surface with a deeply weathered reddish-brown soil mantle. This surface is known as Riverside or Grand Terrace. The Santa Ana River, which crosses the northwest corner of the basin, flows on a flood plain one to two miles wide that is cut about 50 feet below the level of the Riverside Terrace.

Riverside Basin is separated rather indefinitely from Rialto-Colton Basin by a fault. West of Colton and north of the Jurupa Mountains the alluvial fill is connected with that of Chino Basin, but here the basin separation is made on the basis of a ground water divide (Plate E). The boundary between Arlington and Temescal basins is a line through the alluvium at Arlington Gap. Elsewhere, bedrock hills form the boundaries of the Riverside Basin area. Santa Ana River flows westerly from the area through a narrow shallow gorge in the bedrock hills into Chino Basin.

Riverside and Arlington basins are formed by a bedrock canyon system heading in the vicinity of Arlington in the southwest part of the area and running northerly, emptying into the deep main part of Santa Ana Basin through the gap between Riverside and Colton where Santa Ana River flows. That is, the ancient local drainage was to the north, almost in an opposite direction from the flow of the present Santa Ana River.

The alluvial fill deposited by Lytle Creek and Santa Ana River covered the old bedrock surface and buried this canyon system. It finally topped the southwest rim of the canyon, and Santa Ana River has since then from time to time flowed out through the Arlington Gap to join Temescal Creek near Corona.

The bedrock floor is granitic Basement Complex like that in the hills around the basin. It slopes from an elevation of a little more than 600 feet at a subsurface divide in the southwest part of the basin near Van Buren street, to a probable elevation of about 200 feet at the northern margin where it is deepest (Plate C). This bedrock canyon runs along the west side of the basin beneath the river. In the northeastern part of the basin there is a tributary bedrock canyon separated from the deeper canyon by isolated hills protruding through the alluvium. This trough apparently joins the deeper one through the gap just north of Riverside.

The buried bedrock canyon system which forms the Riverside Basin area is a part of the drainage system of the pre-alluvial Santa Ana River Valley to the north. It is cut into the north rim of the old Perris Plateau. The buried canyon walls are steep and the bottoms probably narrow and V-shaped. Since no wells have been drilled to bedrock in deepest parts of the area, the exact nature of the canyon bottoms is uncertain.

There are no faults running through the Riverside Basin which have a noticeable effect upon the ground water, and it seems probable therefore that there are no active faults within the basin.

Character of the Water-bearing Series.

Santa Ana River and its tributaries have supplied the major portion of alluvial fill in Riverside Basin and a considerable part of that in Arlington Basin. The material, like that of the basins upstream, is principally crystalline granitic and metamorphic, with occasional hard sandstone pebbles and cobbles. The deposits around the margins, and the upper 50 to 100 feet of deposits beneath the Riverside Terrace are principally of local origin, having been deposited by the small streams which drain the granitic hills adjacent to the area.

An analysis of the clay, sand and gravel percentages in different parts of the Riverside Basin area and at different depths, brings out several interesting facts, concerning the history of accumulation of the deposits. For this analysis the basin was separated into the Flood Plain area (that area along the river about two miles wide whose surface is at river level) and the Riverside Terrace area (the bench southeast of the flood plain of Riverside Basin and of Arlington Basin.

Table 8 shows the percentages of the different materials present at various depths in the two areas.

TABLE 8

COMPOSITION OF THE WATER-BEARING SERIES IN DIFFERENT PARTS OF THE RIVERSIDE BASIN AREA

RIVERSIDE BASIN								ARLINGTON BASIN		
Flood Plain				Riverside Terrace				Riverside Terrace		
Depth, feet	Percentages			Depth, feet	Percentages			Percentages		
	Clay	Sand	Gravel		Clay	Sand	Gravel	Clay	Sand	Gravel
----------	----------	----------	----------	0–50	86.3	2.7	11.0	72.3	20.4	7.3
0–50	17.8	26.8	55.4	50–100	61.2	5.1	33.7	26.1	30.2	43.7
Below 50	33.8	5.8	60.4	Below 100	38.5	2.7	58.8	20.9	18.2	60.9

From Table 8 it can be seen that the flood plain deposits to the depth of 50 feet are distinctly different than those in any other part of the Riverside Basin. The increase of percentage with coarseness, shown here, indicates a normal series of coarse river deposits, not materially altered by weathering. There is, furthermore, no reason to suspect from the topographic position of these deposits that much alteration by weathering has been possible. The clays, comprising a little less than 18 per cent of the deposits were deposited as silts and clays upon the flood plain.

The upper 50 feet of deposits beneath the Riverside Terrace are principally clay, in both Riverside and Arlington basins, the deposits from 50 to 100 feet, more than half clay in Riverside Basin, and the sand percentage in Riverside Basin much lower for both depths than the gravel content. This is not the normal succession in unweathered alluvial deposits. Evidently the high percentage of clay is due principally if not entirely to weathering of the original gravels and sands. In Arlington Basin the zone 50 feet to 100 feet deep is more similar to the upper 50 feet of the flood plain deposits. Possibly these deposits are in part a buried flood plain accumulation in which weathering played a minor part. Weathered matrials in wells near the margins of the basin complicate conditions, however. Ravines which cut the terrace to depths of nearly 50 feet show this to be true in the upper 50 feet, and samples from wells show residual clays from greater depths.

Below the first 50 feet of flood plain deposits and below the 50 to 100 foot depth of Riverside Terrace deposits in Riverside Basin, the materials become more similar throughout the basin, but here the percentage of sand is strikingly less than that of either gravel or clay. Probably, therefore, the clays are principally the products of weathering of the original deposits. The deeper deposits of Arlington Basin have considerable sand and little clay. These deposits may have accumulated under high water table conditions where weathering was less effective than farther northeast.

From the above discussion of the nature of the alluvium in Riverside and Arlington basins, certain conclusions can be drawn. As alluvial deposits from the rising San Gabriel and San Bernardino Mountains began to pour into the depressed Santa Ana Valley area, they gradually filled the bedrock Santa Ana River Canyon north of Riverside Basin, and entered the tributary canyons on the south side. Thus Riverside Basin was gradually filled with coarse debris from the north and east. At the same time the small streams around the margin of the basin deposited a narrow apron of poorly assorted debris along the edges of the hills. Periodically the river wandered north of the Riverside area, allowing the surface to weather and form clay soil mantles, to be buried by succeeding migrations. During the later stages of accumulation, the river partially buried the bedrock ridges, leaving only steep sided isolated hills protruding through the alluvial surfaces. The debris from the large streams gradually spread southwesterly across the Arlington Basin and through Arlington Gap to Temescal Basin (Plates C and E). The deeply weathered condition of the upper 50 feet of materials beneath the Riverside Terrace indicates that the river migrated north of the area repeatedly during accumulation of the deposits, each time leaving the area with a water table low enough to permit weathering of the surface. During the last stage of deposition on the Riverside Terrace surface, the river appears to have flowed across this surface and at different times out through both the Arlington and Riverside narrows, through the latter of which it now flows.

The growing Lytle Cone probably kept the river south of the Jurupa Mountains during the later stages of deposition upon the Riverside Terrace surface, until finally it began to cut into that surface. The river has since become incised into the older surface from the upper end of Riverside Basin westward to the Coastal Plain, and that surface has developed a deeply weathered mantle. The only deposition upon the Terrace surface since the river became incised into it has been from the small streams along the southeast margin. This local deposition has been so gradual that the deposits have weathered to soil with the remainder of the surface as fast as they have been deposited. From the depth of flood plain deposits shown by well logs, the river appears to have cut some 50 feet below its present level. In its last stage, therefore, it has filled back about 50 feet of its incised valley with Recent clays, sands and gravels, to the present flood plain surface. Throughout this most recent period of accumulation the river has remained within its incised valley course and the water table has been near or at the surface at all times. Consequently, there has been no opportunity for weathering of the Recent flood plain deposits.

Due to the low and uniform alluvial gradient through the area, the average size of gravels in different parts varies only slightly. Cobbles in the coarsest gravels are not commonly more than two to three inches in diameter, and probably generally less than two inches in the southwestern part. In the northern end of the basin, north of the river where coarser gravels from Lytle Creek have been deposited, cobbles four to six or eight inches in diameter are probably fairly common.

On the basis of this size distribution, estimated principally from data secured from wells being drilled, a minimum specific yield of 15 per cent was assigned to unweathered gravels at the extreme northern end of the basin near Rialto. The yield was increased sharply to 18 per cent in the vicinity of Santa Ana River, and then gradually to a maximum of 20 per cent in Arlington Basin (Plate F).

Specific Yield and Storage Capacity.

The storage capacity of Riverside Basin was computed in 50 foot vertical intervals by applying the specific yield values for different types of materials to the well log group averages. From these data, the storage capacity between two theoretical water tables, one averaging 20 feet above the water table of January, 1933, and the other averaging 50 feet below that water table, was computed. The specific yield contours on Plate E represent the average values for the entire zone between the two theoretical water tables. The upper estimated water table varies from zero feet, throughout most of the river flood plain area, to a maximum of 60 feet at the extreme north end of the basin above the water table shown on Plate E, and from 30 to 50 feet above that water table along the southeast margin of the basin. The theoretical water table, below the 1933 table, varies from zero feet at the head of Riverside Narrows, to a maximum of 40 feet below that water table at the northeast edge of the basin in the flood plain area. Toward the north end of the basin from the river, the theoretical drop increases to 150 feet and to maximums of 50 to 70 feet along the southeast side of the basin, decreasing toward the extreme southeast margin and toward Arlington Basin.

In Arlington Basin the zone for which the storage capacity was computed had an average thickness of 25 feet above, and 25 feet below the 1933 water table. Above the water table the zone varied from zero along the northwest margin to 50 feet thick in the southeast part of the basin, and the zone below the water table varied from 10 feet thick along the northwest margin to 50 feet in the southeastern part.

The contours for this 70 foot (average) thick zone show a belt of high specific yield running southwesterly from the north end of the basin west of Colton, along the western side to the vicinity of the Riverside Narrows, then southerly into the Arlington Basin and southwesterly through that basin and out through the narrows to Temescal Basin. The highest specific yields in this belt are near the north end where the maximum exceeds 18 per cent. It gradually decreases to 13 per cent at the Riverside-Arlington Basin boundary. Through Arlington Basin as far southwest as Van Buren Street it is 12 to 13 per cent. It drops sharply to about 7 per cent toward the Arlington Narrows, but rises again to 10 per cent through the narrows.

There is a secondary narrower belt of high specific yield running south from Colton through the east side of Riverside Basin, joining the main belt southwest of Riverside. Specific yields in this belt are 12 to 15 per cent. These two belts of high specific yield running through the basin probably mark the most persistent courses of Santa Ana River during accumulation of water-bearing deposits within the zone computed.

The lowest specific yields occur along the southeast margin of the Riverside and Arlington basins where the water-bearing deposits are of local origin. The specific yields decrease to four per cent or less along the edges of the basin, being lowest in the re-entrants. The influence of local deposits along the northwest side of Riverside Basin is unimportant. In Arlington Basin there are two rather large re-entrants of alluvium into the hills along the northern margins where the deposits are of local origin. These deposits are so shallow (zero to 50 feet thick) that they contain very little ground water.

The storage capacity for the zone averaging 20 feet above the January, 1933, water table is 51,000 acre feet in Riverside Basin and for the 25 feet in Arlington Basin is 14,000 acre feet. For the zone averaging 50 feet thick below that water table, the capacity in Riverside Basin is 156,000 acre feet, and in Arlington Basin for 25 feet is 22,000 acre feet.

Variation of specific yield is so great in different parts of the basin, and water table fluctuations so uneven in different areas that the above figures do not form a reliable basis for computing storage changes from average water table changes. They are presented to show the relative differences between the storage capacity of the zone above the 1933 water table and that below it. In Riverside Basin the storage capacity of the 20 foot zone above the water table is about 14 per cent less than the average indicated by the specific yield contours. In the 50 foot zone below the water table the storage capacity is 5.6 per cent above the average. In Arlington Basin the storage capacity of the 25 foot zone above the 1933 water table is about 21 per cent lower than the average indicated by the specific yield contours, and the zone 25 feet below, about 21 per cent higher than the average indicated. The reason for these large differences is that the zone above the water table enters the lower part of the clayey mantle which is 50 to 100 feet thick beneath the Riverside Terrace. In view of these large discrepancies, it is necessary to take into consideration the deviations from average specific yield, when storage changes are computed from water table fluctuations involving considerable portions of the zones. In the main, however, both short period and cumulative water table changes, are small in these basins.

Ground Water in Riverside Basin.

Underflow from Colton Basin passes into the northeast part of Riverside Basin where it separates. One portion moves southwesterly along the west side of the basin toward Riverside Narrows where it appears as rising water. The other moves south from Colton through the east side of the basin and swings west, joining the other portion of the ground water above Riverside Narrows. The bedrock hills southwest of Colton separate these two ground water bodies. Ground water, principally return irrigation water, moves northwesterly from the divide which forms the Riverside-Arlington basin boundary.

Other sources of ground water in Riverside Basin include percolation of run-off in the river bed above the area of rising water, percolation of run-off from the small streams along the southeast margin of the basin, rainfall penetration, and a considerable recharge from return irrigation water.

The water table beneath the flood plain area of Riverside Basin is about 50 feet below the surface at the upper end of the basin and converges downstream, reaching the surface in the river bed near where the San Bernardino-Riverside county line crosses it. Below that point there is rising water in the river. The water table beneath Riverside Terrace is considerably deeper, varying from about 50 feet near the edge of the terrace near Riverside Narrows to a little more than 100 feet. North of the river the topography rises toward Rialto faster than the water table and consequently the ground water is more than 200 feet from the surface at the northern end of the basin.

In 1922 the ground water was practically at the surface throughout the flood plain area and from 20 to 50 feet higher northeast of Riverside beneath the terrace. The water table has changed very little east and south of Riverside. Decrease of underflow from the Colton area is responsible for the drop in the northern part of the basin, but since there is still an excess (rising water) in the lower part of the flood plain area, the southern part of the basin has not been affected by loss of underflow from Colton Basin. Percolation of irrigation water, which is the principal source of ground water in the southeast portion of the basin, furnishes a relatively constant supply, and so long as there is rising water at the narrows to maintain a constant water level, there will probably be little change in the water table in the southeastern part of the basin provided the pumping draft is not increased materially.

From the conditions outlined above, it can be seen that the situation in Riverside Basin is somewhat unusual. There is at present a surplus of ground water which appears as rising water and wastes as evaporation and transpiration. But, since the largest source of supply is dependent upon underflow from another basin, the northern part of the basin is subject to cyclic fluctuation, and furthermore, increased drafts on the upper basins which feed Riverside Basin would reduce the present surplus. Judging from the 1922 water table, when the basin was practically filled to river level, the practical storage capacity above the present water table is small, and is probably not more than half of the 51,000 acre feet computed for an average 20 foot rise over the entire basin. A lower water table, however, resulting from removal of the surplus from underflow would increase the storage capacity and permit greater percolation of flood run-off from Santa Ana River.

Ground Water in Arlington Basin.

Arlington Basin is supplied with ground water by percolation of irrigation water and smaller supplies from local run-off and rainfall percolation. The ground water moves northwesterly from the heavily irrigated slopes back of Arlington toward the low land in the northern part of the basin, where the water stands within a few feet of the surface. It moves southwesterly along the north side of the basin from the ground water divide separating Arlington Basin from Riverside Basin, and the underflow discharges through Arlington Gap into Temescal Basin.

Due to the lack of any appreciable amount of surface run-off percolating into the basin, and to the relatively constant supply from return irrigation waters, the seasonal fluctuation is only a few feet. There is little evidence of pressure in these wells.

The trend of water levels over the long period since irrigation was inaugurated has been opposite to that in most areas. The water table which originally probably sloped toward the Riverside Basin, and was maintained by the limited natural supply from local sources, rose when water was imported for irrigation. Return irrigation water became an important source of supply to the ground water. Throughout most of the area northwest of Magnolia Avenue the water table rose to within a few feet of the surface, and the direction of movement was reversed, the ground water moving southwesterly out through Arlington Gap. It became necessary because of the high water table north of Magnolia Avenue to abandon a considerable acreage of citrus in that district.

In the southwestern part of the basin the partial record available for well No. E-176 * and several others shows a net decline of only about five to seven feet from 1921 to 1932. This decline, when considered together with other information on the hydrology of the basin, is of little importance in the matter of the basin's supply.

* Division of Water Resources Bulletin 39, p. 552, 1932.

TEMESCAL BASIN

Location and General Description.

Temescal Basin lies in the southwest corner of Upper Santa Ana Valley where it occupies the northwest end of the Elsinore structural trough. It has a surface area of approximately 16,200 acres. Its northern boundary is Santa Ana River, its southwest boundary, Chino and Elsinore fault zones. Its southeast limit is a group of low sandstone and granite hills which cross the trough and practically cut off the alluvial fill. The irregular northeast margin is formed by the low granitic hills of the Perris structural block. Other small alluvial basins lie southeast of Temescal Basin in the Elsinore trough but these were not included in the detailed study.

Temescal Basin is connected by alluvial fill through the Arlington Gap with Arlington Basin, and is connected across its entire northwest end with the alluvial fill of Chino Basin. The surface of this basin, like that of Riverside Basin, is formed by two deposition levels. One, the older and higher surface, is a part of the same surface as the Riverside Terrace. It is a dissected surface with deeply weathered reddish-brown soil mantle and covers most of the long alluvial slopes which extend northeasterly across the basin from the base of the Santa Ana Mountains toward Temescal Wash. There is a fringe of this old elevated surface along the northeast margin of the basin.

Incised into the older alluvial surface is the recent alluvial surface or flood plain of Temescal Wash and its tributaries, which is continuous with the Santa Ana River flood plain. The Temescal surface is incised from zero to fifty feet below the level of the older alluvial surface, and occurs in a belt about one mile wide along Temescal Creek, spreading out over considerable area around Corona where a recent cone joins Temescal from the Santa Ana Mountains.

Character and Depth of the Bedrock Floor.

Its depth is not known accurately but from several known bedrock points, contours on the base of the alluvium were estimated for the northern part of the basin (Plate C). The basin is apparently an alluvium-filled trough or canyon sloping to the northwest into the deeper part of Upper Santa Ana Valley. The base of the alluvium at the northern end of the basin is about 300 feet elevation in the bottom of the buried canyon, rising to an elevation of about 600 feet to the east in Arlington Gap, and to about 900 feet elevation where it comes to the surface at the southeast end of the basin. The maximum depth of the basin is apparently from 300 to 400 feet, although it is possible that this depth is exceeded beneath the high cone south of Corona.

The water-bearing alluvial series, for the most part, is underlain by Puente shale and sandstone with lenses of hard conglomerate (Plate D, Section RS). Several wells 700 to 1000 feet deep, near the north margin of the basin, produce moderate quantities of warm sulphur water from conglomerates in the Puente formation, but production from this formation has to date been of little economic importance. The isolated character of water-bearing beds and the comparatively poor quality of the water indicate that the Puente beds are not important potential sources.

Sandstones of probable Martinez (Eocene) age underlie the alluvium along the southern margin. Apparently, the granite which forms the northeast margin of the basin is almost completely overlapped beneath the alluvium, even in Arlington Gap, by the Puente and Martinez formations, and therefore it does not form a significant part of the alluvial basin floor.

Character of the Water-bearing Series.

The alluvial fill throughout the greater part of Temescal Basin has been deposited by the streams draining the adjacent northeast slopes of the Santa Ana Mountains. Temescal Creek has deposited most of the alluvium in the northeast part of the basin, but Santa Ana River has from time to time contributed deposits through Arlington Gap. Santa Ana River deposits also form part of the fill along the northern margin of the basin.

Well log averages show some difference in the character of the deposits, in different parts of the basin, but these differences are not as striking as they are in some basins.

Well logs in the area southwest of Temescal Wash show 58.1 per cent of clay, 0.8 per cent sand, and 41.1 per cent of gravel. North of Temescal Wash, in the northeast corner of the basin, the logs show 52.8 per cent clay, 16.6 per cent sand, and 30.6 per cent gravel. This material is similar in character to that southwest of Temescal Wash, but contains finer material, probably derived from the low nearby hills. A high percentage of residual clay is indicated in both areas.

Well logs in the vicinity of Temescal Wash show conditions to be quite different there than on either side. There is recorded there an average of 30.9 per cent of clay, 6.8 per cent of sand and 62.3 per cent of gravel. Apparently the present course of Temescal Wash marks approximately the region through which the stream has deposited more or less continuously during accumulation of the deposits. This more continuous deposition by Temescal Wash and a high water table, at least during part of the time, has greatly reduced the effectiveness of weathering in this belt. Therefore the percentage of clay is relatively low, and gravel, high. A group of well logs in the Arlington Gap shows the deposits there to be similar to those in the Temescal Wash area although somewhat finer. These logs show 37.2 per cent clay, 18.6 per cent sand, 44.2 per cent gravel. The greater part of the clay occurs in the upper 50 feet or 60 feet.

On the basis of data from well logs and wells observed during drilling, the maximum 10 per cent grade size of gravels is estimated to vary from 10 and 20 inches at the heads of the cones along the southwest margin of the basin to ⅝ to 1¼ inches in the vicinity of Santa Ana River. At the head of the basin in Temescal Wash the maximum 10 per cent grade size is estimated to be 1¼ to 2½ inches.

The specific yield of unweathered gravels, assigned on the basis of the size estimates, varies from 13 per cent at the southern margin of the basin to 20 per cent in the Temescal Wash area, and 22 per cent in the vicinity of Santa Ana River.

Specific Yield and Storage Capacity.

The storage capacity of a zone averaging 50 feet thick and extending approximately an equal distance above and below the water table of January, 1933, was computed. Specific yield contours for this zone are shown on Plate E.

Thickness of the zone varies according to available storage space and probable relative water table fluctuations. Along the Santa Ana River the zone varies from five feet thick at the head of the narrows west of Prado to 35 feet where the river enters the basin; most of the zone lies below the water table in this area. Up Temescal Wash the zone increases to a maximum of 100 feet east of Corona. It has a maximum thickness of 100 feet on the cone a short distance south of Corona also, but decreases to zero at the south end of the basin. The computed storage capacity for that portion of the zone averaging 25 feet thick above the water table of January, 1933, is 34,000 acre feet, and 36,000 acre feet for the similar portion below. The upper zone figure is probably near to the practical limit of available storage above the 1933 water table.

The specific yield as shown by the contours for this zone (Plate E) varies from six and seven per cent along the southwest and south margins of the basin to a little more than 14 per cent in the Temescal Wash area near Corona, and about 13 per cent along the Santa Ana River.

Ground Water in Temescal Basin.

Percolation of run-off from the Santa Ana Mountain streams that enter the basin along its southwest margin and from Temescal Wash are probably the major sources, but rainfall penetration, return irrigation water imported from upper basins, and underflow from Arlington Basin all contribute materially to the supply.

The ground water converges from the southwest, south and southeast portions of the basin and moves northwesterly in the direction of Temescal Wash to the Santa Ana River, where the excess appears as rising water.

Seasonal fluctuation of water levels in Temescal Basin varies from a few tenths of a foot in wells along Santa Ana River to 5 to 15 feet in different wells in the vicinity of Corona. The seasonal fluctuation may be even greater in the district south of Corona. The water level in well No. E-282f * in Corona shows very little recovery in the fall, due to pressure effects, after the heavy pumping season and before winter rains become effective.

Direct recharge from run-off percolation takes places along Temescal Wash. The record of well No. 282f shows the effect of heavy rains within a few weeks. There does not appear to be a delayed recharge of any importance in the basin. Probably the underflow from Arlington Basin is practically constant.

The cumulative change in the water table elevation is zero along the Santa Ana River, but to the southeast there has been a gradual decline during the past eight or ten years. Well No. E-282f shows a net decline during the period from January, 1925, to January, 1933, of

* *Op. cit.*, Bulletin 39, p. 583, and Bulletin 39-A, p. 87.

10 feet, to the depth of about 82 feet on the latter date. This eight-year decline is about equal to twice the usual annual fluctuation of the water level in this well. Considering the subnormal precipitation record for the eight-year period, the decline appears to be relatively small.

SPADRA BASIN

Location and General Description.

Spadra Basin which occupies the eastern end of San Jose Valley between the Puente and San Jose Hills is a horn-shaped alluvium-filled valley whose surface area is about 4200 acres. The basin widens and deepens from the narrows at its southwest end toward the northeast. At present, both the surface drainage and ground water movement is westerly and southwesterly through the basin, the outlet being through the narrows at the southwest end.

The northern boundary of the basin is formed by San Jose Hills and the southern by Puente Hills. The basin is connected by alluvial fill, through the narrows at its southwest end with Puente Basin, and the boundary there separates the two basins at the narrowest point. At the extreme northeast corner of the basin, it is separated from Pomona Basin by San Jose fault which forms a barrier of low permeability, running through the alluvium northeasterly from the east tip of San Jose Hills. The basin is connected along its eastern margin with the alluvial fill of Chino Basin. The boundary which separates these two basins is a ground water divide.

Character and Depth of the Bedrock Floor.

Before Upper Santa Ana Valley was depressed, it is probable that a part or all of it drained out through San Jose Valley at a level higher than the present valley floor. Terrace remnants of this old valley are seen on either side of the narrows at the southwest end of the basin. As the hills rose with respect to the valley, the drainage was reversed and a canyon draining into Upper Santa Ana Valley was cut back into the floor of the old San Jose Valley. This canyon is the floor of Spadra Basin. The alluvium of the advancing San Antonio Cone gradually filled the Spadra Canyon, and broke through the rim at the southwest edge of the basin. San Antonio Creek then cut down 150 feet or more, forming the narrows, and since has filled back about 100 feet of this cut.

The maximum depth of the basin is 550 feet at the east margin. It decreases toward the southwest to a depth of about 90 feet in the narrows at the southwest boundary of the basin.

From an inspection of the geologic map, Plate C, it can be seen that the same general succession of formations occurs in the hills on either side of the basin. Wells drilled to bedrock in the basin show these same formations to form the floor of the basin. Basement Complex (gneiss) lies beneath the alluvial fill at the eastern end. West of the Basement Complex, a belt of Tertiary volcanics form the floor of the basin, and Puente sandstone and shale lie beneath the alluvium in the southwestern part of the basin.

Locally, potable ground water has been obtained from joint cracks and other crevices in the volcanics, and from conglomerate lenses in the Puente formation. Some additional production might be obtained from these formations if wells were drilled into them, but such production would probably be small, local and of questionable quality. Judging from the outcrops of these formations in the hills, and behavior of ground water there, the total storage capacity of the formations is negligible, and is therefore not considered at this time.

Character of the Water-bearing Series.

The Water-bearing series of Spadra Basin is made up largely of granitic and metamorphic materials from San Antonio Canyon. Deposits from the hills along the margins, however, form a considerable portion of the deposits, and are the only alluvial deposits found near the margins. The water-bearing gravels are principally in the central part of the valley and at some depth beneath the surface. They are, in the main, San Antonio Canyon gravels.

Well log averages show a relatively high percentage of clay, and very little sand in the basin. These logs show 64.5 per cent clay, 3.5 per cent sand, and 32.0 per cent gravel. The clayey material has been formed principally from decomposition of gravels. The low per cent of sand indicates the coarse character of the unaltered deposits. Two wells, however, about one mile from the east margin of the basin, near the Union Pacific Railroad, encountered gray sedimentary clay containing fresh water fossils at the depth of about 180 feet. One of these penetrated 70 feet of this material. Evidently there was a small lake in the southeast corner of the basin at one time.

There is a higher percentage of clay in the broad eastern part of the basin than in the narrow southwestern part. There has probably been less opportunity for weathering in the narrow portion where the stream has been more closely confined.

Although the data from wells are rather scattered, they indicate only a slight decrease of average coarseness of gravel deposits from east to west in the basin. Cobbles six inches in diameter are comparatively rare, and the average maximum 10 per cent grade size of the gravels is estimated to be $1\frac{1}{4}$ to $2\frac{1}{2}$ inches. On this basis the specific yield values for unweathered gravels vary between 17 per cent in the northeast corner and 19 per cent in the southwestern part of the basin (Plate F).

Specific Yield and Storage Capacity.

Specific yield contours, based on computations from well log averages with the above gravel yield values assigned, are shown on Plate E, for a zone averaging 100 feet thick above and below the water table of January, 1933. These contours indicate a belt of maximum yield running through the central part of the basin from east to west. The specific yield in this belt is about nine per cent and drops off to about five per cent along the hill margins where the deposits are of local origin. The storage capacity for the 50 foot zone above the water table was computed to be 15,000 acre feet and for a similar zone below the water table to be 11,000 acre feet. The capacity for the lower zone is greatly reduced by interference of bedrock.

Ground Water in Spadra Basin.

Underflow from Pomona Basin forms the most important source of ground water in Spadra Basin. The underflow from Pomona Basin that escapes through San Jose fault near the east tip of San Jose Hills divides. One part moves westerly into Spadra Basin and the remainder moves southeasterly into Chino Basin. Percolation of rainfall upon the valley floor and percolation of run-off from the hills draining into the basin and from San Jose Creek furnish additional supplies.

The ground water moves westerly through the basin from the divide at the east end, most of the movement being through the central belt where higher specific yields prevail. The ground water is not obstructed or diverted by any important bedrock or structural barriers within the basin.

Water levels in Spadra Basin fluctuate annually from about 5 to 10 feet. There is very little recovery due to pressure readjustments after the pumping season. The levels rise in the spring and decline in the summer. In dry years there is little or no spring rise, but in wet years the rise may exceed 10 feet in parts of the basin. This rise occurs during the winter and spring of the year of heavy rainfall, and thus shows it to be a direct recharge from run-off and rainfall percolation.

The records of several wells in the vicinity of Spadra show a cumulative rise and fall of the water table through wet and dry periods respectively, which appear to be more or less independent of the annual fluctuations. The water table rose gradually about 25 feet from a low at the end of 1906 to a high at the end of 1916. Since that time there has been a gradual recession amounting to a drop of 80 feet in wells at Spadra.

The height of the water table in Spadra Basin is dependent in large part upon the amount of underflow from Pomona Basin, which maintains the head of the ground water divide at the east end of Spadra Basin. It is due in part to decrease of the underflow that the water table has dropped.

A comparison of the water table at this divide in 1904, as shown by Mendenhall, with the water table of January, 1933, gives a net decline of about 85 feet for the normal 29 year period. During the same period the water table has dropped about 40 feet at the southwest end of the basin in the narrows.

The slope of bedrock in Spadra Basin, and the greater depth of Chino Basin to the east, makes the supply of underflow to Spadra Basin dependent in large part upon maintenance of the ground water divide at the east end of the basin above elevation 500, for that is the approximate elevation of bedrock at the Spadra narrows in the southwest portion of the basin. The amount of underflow into Spadra Basin varies with the height above 500 feet elevation of the water table at the east end of the basin.

Should the reduction of head at the east end of the basin continue, either through further decrease of underflow from Pomona Basin, or from further decline of the water table in the adjacent part of Chino Basin, the supply from underflow will eventually be cut off and the gradient reversed in Spadra Basin. In this event the basin would be dependent for natural supply upon direct recharge from local sources.

POMONA BASIN AREA

Location and General Description.

The Pomona Basin area occupies the northwestern portion of San Antonio alluvial cone and has a surface area of 10,490 acres. It lies between the San Jose Hills and the foothills of the San Gabriels and extends east to San Jose fault which forms the ground water barrier or "dike," running northeast from the east tip of San Jose Hills to the Cucamonga fault near the mouth of San Antonio Canyon (Plate C). Its western boundary is considered to be a line running southwest from Liveoak Canyon to the San Jose Hills. This boundary of the Pomona Basin area approximates the buried bedrock divide which extends from the mountain-front a short distance west of Liveoak Canyon mouth southwesterly to the San Jose Hills. The San Jose fault separates the Pomona Basin area from Chino Basin and is commonly known as the Pomona dike.

The Pomona Basin area includes three small basins—Liveoak, Claremont Heights and Pomona basins. Buried bedrock ridges and faults separate the area into these separate units.

Claremont Heights Basin lies northeast of the buried bedrock barrier, bounded by the Indian Hill fault (shown on Plate C lying just north of Foothill Blvd.) along the south margin in the eastern part of the area. The basin has a maximum known depth of 750 to 800 feet. Its deepest portion lies about midway between the south boundary and the Cucamonga fault, and slopes easterly from the low point in the divide along the southwest margin, to the San Jose fault.

Pomona Basin occupies the deep triangular depression in the bedrock between Pomona, La Verne and Claremont. Its maximum depth ranges from about 800 feet near La Verne to more than 1100 feet near the south margin of the basin. This basin is apparently a buried canyon that drained toward the southeast. One branch came in from the vicinity of Puddingstone reservoir and joined a branch that drained the higher bedrock north and east of La Verne.

In the northeast corner of the basin at Claremont, the water table stands higher and fluctuates differently than that farther southeast in the basin. Originally there was artesian water here and two cienagas existed where water rose to the surface in the town of Claremont. Evidently there is some hidden obstruction, either a fault or the bedrock ridge, which retards the ground water northeast of it.

The relatively shallow region north of La Verne is considered to be a separate basin (Liveoak) because the water storage problem is different from that of the deeper Pomona Basin south of Indian Hill fault. The depth is about 200 feet along the buried divide between Liveoak and San Dimas basins, and irregularly increases toward the east to a depth of more than 500 feet.

Character and Depth of the Bedrock Floor.

East of an irregular line drawn from the contact between "Later igneous rocks" and "Basement Complex" near the east end of San Jose Hills at Pomona (Plate C), through La Verne to the foothills, bedrock, wherever encountered, has been Basement Complex (except in a well one mile west of Claremont where Tertiary volcanic material was encountered). Granite and gneiss are the types generally encountered. West of this line the Tertiary series overlies the old crystalline rocks and forms the floor of the alluvial basin. The succession toward the west is similar to that exposed in the hills to the south. Lava, chiefly basic (andesite or basalt), extends west from La Verne almost to the western edge of the Pomona Basin area. Wells along the west edge of the basin encountered Puente shale.

Bedrock beneath the alluvium has a weathered (decomposed) surface 10 to 50 feet thick wherever it has been penetrated, showing that the alluvium is deposited on a surface long exposed to erosion and substantiating the idea that irregularities in the bedrock represent old canyons and hills of a pre-alluvial surface. Beneath the weathered material bedrock becomes hard.

Bedrock has never been encountered in wells drilled near this fault on either side except within one-half mile of the San Jose Hills and in a well one mile southwest of Claremont on the north side of the fault, where bedrock was encountered at a depth of about 740 feet. Another well a short distance north of the fault between Claremont and Pomona reached a depth of 115 feet below sea level (1100 feet in depth) and was finished in alluvial sand. Other wells on either side of the fault approach or reach sea level but have not encountered bedrock.

The alluvial fill in the Pomona Basin area, as a whole, varies in thickness from less than 300 feet north of La Verne and Claremont, to a known depth of more than 1100 feet between Claremont and Pomona. The bedrock floor is irregular but appears to be a faulted buried canyon system with its outlet to the south, a short distance east of San Jose Hills (Plate C). The bedrock slopes steeply southward where crossed by a fault at Indian Hill a short distance north of Claremont and in La Verne. North of this fault the bedrock surface generally stands above 600 feet elevation. South of it, only the buried hilltops reach 500 feet elevation.

The underflow from San Antonio Canyon, diverted southwest by San Jose fault, crosses three buried bedrock ridges before finally reaching the deepest part of the basin between La Verne and Pomona (Plate C). The first of these buried ridges or divides extends southerly from the west side of San Antonio Canyon to San Jose fault. The second lies in its eastern part, a short distance north of Foothill Boulevard and swings northwesterly toward the basin margin. The third lies a short distance southwest of Claremont and is crossed by the Santa Fe and Pacific Electric railways (Plate C).

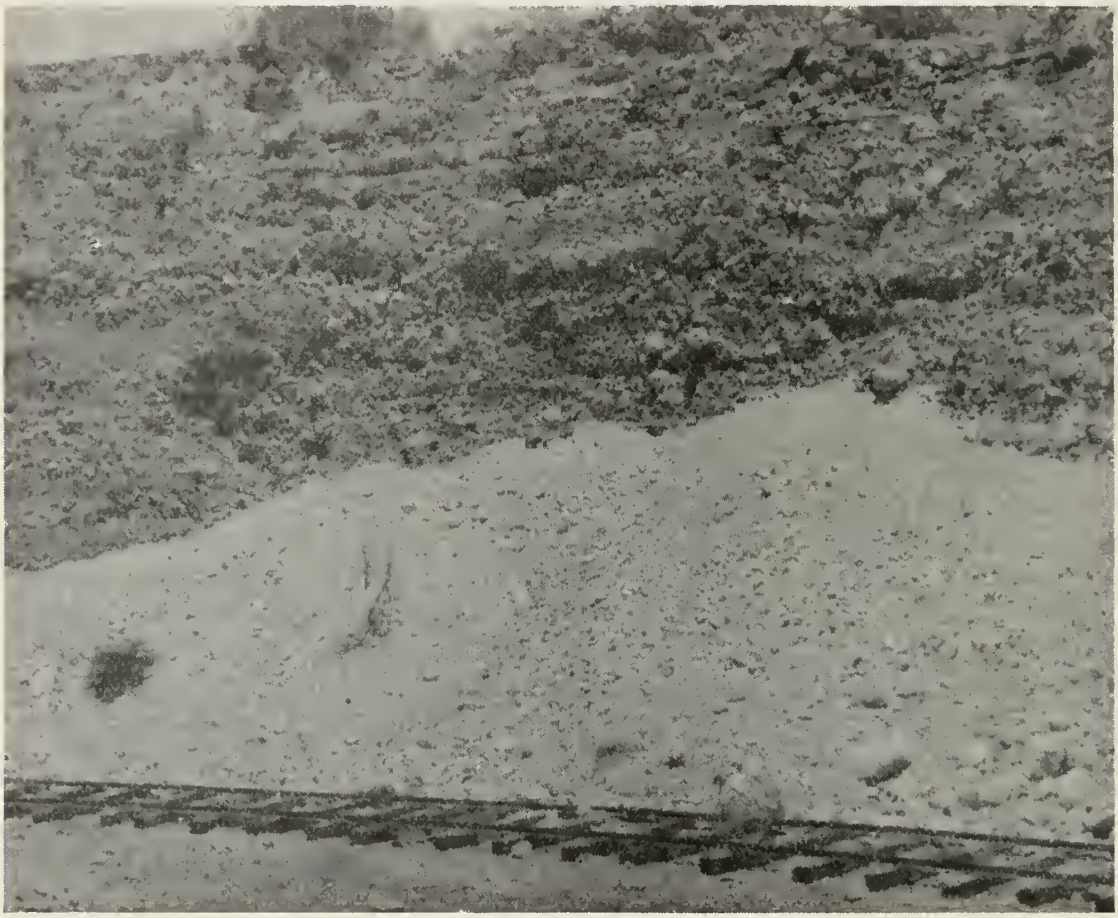
Character of the Water-bearing Series.

The Quaternary alluvium is made up almost entirely of gneissic and granitic debris from the south slopes of the San Gabriels. The only alluvial deposits from another source are those derived from the San Jose Hills. They occur in such minor amounts that their influence upon development of alluvial cones has been negligible.

Permeability of the water-bearing deposits is comparatively low. Surface decomposition, with the formation of residual clays, during accumulation of the alluvial deposits has been the chief factor in reduction of permeability. Pore-filling by lime cement deposited by circulating ground waters has been a minor, but, in some sections, an important factor.

In the region northwest of Claremont and north of La Verne, red and brown residual clays greatly predominate over other materials. Several wells in this district were drilled almost entirely in red residual clay. Passing south into the deep part of the basin, logs show that red residual clays are in part replaced by yellowish clays, partially decom-

PLATE XIX



Gravel bank on upper San Antonio Cone near Claremont.

posed (tight) gravels, and conglomerates cemented by yellow clay or lime.

Well log averages show the material to be almost entirely clay and gravel, the sand content being less than one per cent throughout the area. The original deposits were practically all gravel but have been in large part altered to clay. In the western part of the area, well log averages show 72.2 per cent clay, 0.8 per cent sand, and 27 per cent gravel. More than half of this gravel is decomposed and tight. Well logs in the eastern part of the area, where deposition has probably been more continuous, show 54.6 per cent clay, 0.2 per cent sand, and 45.2 per cent gravel. The greater part of this gravel also is decomposed and tight.

The average coarseness of gravels decreases sharply from the mouth of San Antonio Canyon southwesterly to the San Jose Hills. At the northeast end of the basin the largest boulders are several feet in diameter and the maximum 10 per cent grade size of gravels there is estimated to exceed 10 inches.

Distribution of the surface gravels and samples from wells show the coarsest gravels to contain few cobbles in excess of three or four inches diameter in the southwest part of Pomona Basin. The estimated maximum 10 per cent grade size in this area is 1¼ to 2½ inches. The specific yield of unweathered gravel assigned on the basis of coarseness (Plate F) varies from 13 per cent in Claremont Heights Basin to a maximum of 17 per cent along the southwest margin of Pomona Basin.

Specific Yield and Storage Capacity.

In the Pomona Basin area the storage capacity of a zone uniformly 100 feet thick from 50 feet above the water table of January, 1933, to 50 feet below it was computed. There was little difference in capacity between that part above the water table and that part below. These computations gave 8100 acre feet in Liveoak Basin, 18,000 acre feet in Claremont Heights Basin, and 33,000 acre feet in Pomona Basin.

The specific yield contours for this zone (Plate E) show the lowest yields to be in the western part of the area. That in the northwest part of Liveoak Basin is about three per cent, while it drops to less than four per cent in a small area in the southwestern part of Pomona Basin and along the northwest margin of Claremont Heights Basin.

The specific yield increases east and southeasterly across the basin to about seven per cent in the northeast part and eight to nine per cent along the southeast margin. This higher specific yield corresponds to the increase in percentage of gravel from west to east across the Pomona Basin area.

Ground Water in the Pomona Basin Area.

The several sources of ground water in the Pomona Basin area are: (1) direct penetration from rainfall; (2) percolation of surface water from San Antonio Creek and smaller streams along the mountain front; and (3) underflow from San Antonio Canyon.

The ground water moves southwesterly from the mouth of San Antonio Canyon through Claremont Heights Basin into Pomona and Liveoak basins. A part escapes underground through San Jose fault into Chino and Spadra basins. Another part has in the past moved westerly and southwesterly through Pomona Basin and then swung northwesterly across the narrow western part of Liveoak Basin into San Dimas Basin. At present, the water table in Pomona Basin is below the elevation of the bedrock rim between Liveoak and San Dimas basins, consequently there is no movement of ground water in that direction.

The rise and fall of the water table after the wet winter of 1921–1922 throughout the Pomona Basin area is probably the best example on record of the nature of recharge in this area. Records of representative wells published in Bulletin 39, Division of Water Resources, show the effect of this recharge. The effect of faults and high bedrock divides in the alluvium are the predominating factors in retardation of recharge. Wells near the mouth of San Antonio Canyon felt the effects of the recharge almost immediately, and the water table there rose about 90 feet between January 1 and March 15, 1922, when it reached a peak and began to decline. The ground water moves southwest from this area over the bedrock divide (Plate C) into the central part of Claremont Heights Basin. Here there was a total rise of a little more than 100 feet from January 1 until a peak was reached about the middle of May. Water levels in wells throughout this basin rose almost simultaneously, and reached peaks within fifteen days of the same time, in different parts of the basin, although some were more than a mile farther from the source than others. Evidently this water table rose as a result of pressure transmission southwest from the rising water table near San Antonio Wash.

The rise was more gradual and much less intensive at the south edge of the Claremont Heights Basin than to the north. This may have been due in part to the presence of tighter material, but was probably due also to the fact that pressure was lost across the divide and through the Indian Hill fault almost as rapidly as it accumulated. The peak was not reached until about August 1, with a rise of only 30 feet.

The principal recharge did not begin in Claremont wells until the middle of July, and continued until about March 1, 1923. Wells in the lower part of this area flowed. Rise of the water table at Claremont evidently awaited the movement of water across the divide from the Claremont Heights Basin.

No good records were available for wells southwest of Claremont, in the main deep part of Pomona Basin, but at La Verne near the west end of the basin, the water table did not begin to show the effects of the 1922 recharge from San Antonio Canyon until about November. The rise amounted to only about 30 feet, the effect having been dispersed over the large main part of the basin.

The water problem in each of the three basins is different. Claremont Heights Basin, lying near the mouth of San Antonio Canyon, is subject to large and rapid recharge during wet seasons, as shown by the 1922 recharge. Greatly increased pumping lifts and decreased production may seriously inconvenience water users in this basin, and after several years of subnormal inflow an acute but temporary water shortage may occur throughout parts of the basin, but such a shortage would be quickly replenished in a season similar to 1921–1922.

Although the Claremont area (south of Indian Hill fault) is included in Pomona Basin because it is so closely associated with it, conditions are somewhat different than in the rest of the basin. This area is in part a pressure basin and the water table rises very rapidly during periods of recharge. For instance, in the fall of 1922 the levels rose as much as 60 feet and wells flowed.

In Pomona Basin the underground waste diminishes as the water table declines, and therefore, with a low water table a greater portion of the underground supply is available for local consumption.

The Liveoak Basin is unfortunately situated, in that it is both shallow and remote from an important source of inflow. It is in reality not a basin, but rather is a shelf of the Pomona Basin and is drained as the water table is lowered in the deep Pomona Basin.

CUCAMONGA BASIN

Location and General Description.

Cucamonga Basin occupies a surface area of about 7900 acres, in the northern part of upper Santa Ana Valley, and lies principally on the upper part of the alluvial cone of Cucamonga Creek, but extends easterly onto the western part of Deer Creek Cone.

So far as the southwest, south and southeast boundaries of Cucamonga Basin have been determined from water level and well log data, they have been found to be one or more fault zones running through deep and continuous alluvial fill. Cucamonga fault, which runs along the northern border of the basin, separates the comparatively deep alluvial fill of the basin from the bedrock of San Gabriel Mountains. The alluvium north of this fault is limited areally and very shallow. There is no authentic record of any well which has penetrated bedrock in the basin, except that of well No. D-707, in the northwest corner of the basin where Basement Complex was encountered at the depth of 1000 feet. Many deep wells widely distributed through the basin have been drilled to depths of 800 to 1410 feet through the alluvial fill, but with the exception of the one case noted above, these wells have failed to reach bedrock. Bedrock in this basin lies definitely below the economic limit of pumping lifts and therefore is not a limiting factor to the available storage.

The basin boundary runs southeasterly from the north end of Euclid Avenue at Cucamonga fault, encircling the south margin of Red Hill at Foothill Boulevard, thence northeasterly to the vicinity of Highland Avenue. A north-south arbitrary line one mile east of Archibald Avenue terminates the basin on the east. Underground conditions east of that are unknown and it is possible that with additional information to the east that line will be extended to some natural boundary.

The basin boundary from Euclid Avenue southeasterly around Red Hill and northeasterly to Highland Avenue is apparently one fault zone. Red Hill is alluvial fill. It is upfaulted along this fault and the escarpment along its south margin continues northeasterly where it is well defined for some distance, running through the alluvium. Northwest of the vicinity of Red Hill, the recent activity of Cucamonga Creek on its cone has destroyed all surface trace of the fault. Several dry shafts on the southwest side, much deeper than the water table within the basin, roughly define its position, however.

Within the basin itself there is one rather sharp break in the water table which in the absence of known high bedrock, is probably due to faulting. It runs approximately east-west, or a little north of east, crossing the basin about a mile south of Cucamonga fault. Well No. D-707 and another on the east side of the wash have water levels which stand 100 or more feet above those of wells to the south (Plate E). South of this line there is no important break in the water table and its slope is very gentle toward the southeast.

Character of the Water-bearing Series.

The Water-bearing series is composed entirely of the typical alluvial fill of the foothill belt. The southwestern half of the basin is filled with the deposits of Cucamonga Creek, and the northeast half by the small streams between Cucamonga and Deer canyons, and by some deposits from Deer Canyon itself along the eastern margin.

Well log averages of the water-bearing deposits show 46.2 per cent clay, 2.0 per cent sand and 51.8 per cent gravel. A large part of the latter is decomposed and tight. These percentages are characteristic of alluvial deposits near the valley margins in South Coastal Basin. The almost negligible percentage of sand present in the deposits shows that, like those of other similar areas, the clays have formed from decomposition of gravels after their deposition.

The gravels of Cucamonga Basin are relatively coarse throughout, but in the northwest corner of the basin at the head of Cucamonga Cone they are massive boulder gravels with the largest boulders running up to several feet in diameter.

Well data and surface exposures show the maximum 10 per cent grade size to vary from more than 10 inches in the northwest part of the basin to $2\frac{1}{2}$ to 5 inches at the southeast margin. It can be seen from this that in the greater part of the basin the gravels are so coarse that they fall within the limit of the minimum specific yield of 13 per cent for unweathered gravels. The highest specific yield assigned to unweathered gravel is only 14 per cent along the southeast margin of the basin. Consequently, although the percentage of clay is not unusually high for a basin beneath the upper slopes of an alluvial cone, the storage capacity is relatively low.

Specific Yield and Storage Capacity.

For a zone 100 feet thick, taken from equal distances above and below the January, 1933 water table, the computed storage capacity is 53,600 acre feet, with very little difference between the storage capacity above, and that below the water table.

The specific yield contours (Plate E) for the 100 foot zone show the maximum yield of 10 per cent in the southwest part of the basin to decrease to about five per cent at the southeast and east margin, and to four per cent along the north margin of the basin.

Ground Water in Cucamonga Basin.

Percolation of the surface run-off of Cucamonga Creek and percolation of rainfall appear to be the principal natural sources of the ground water in Cucamonga Basin. An additional supply is obtained from San Antonio Creek water diverted into wells in winter, and from return irrigation water arising from the same source.

The ground water moves southerly and southeasterly through Cucamonga Basin from the northwest part of the basin. There is a sharp break between two wells in the northern part of the basin as mentioned earlier, but otherwise the water table slopes gently and without significant break through the basin.

Seasonal fluctuation of water levels in Cucamonga Basin wells is large, being usually in excess of 20 feet, and in wet years sometimes as much as 60 and 70 feet. In part the extreme fluctuations appear to be due to pressure effects. In the summer the basin is very heavily pumped, and the formation, containing considerable clay, hampers the free movement of ground water and adjustment of the water table.

Consequently, there is a sharp recovery of water levels after the pumping season. However, fluctuations representing changes of storage total 20 to 40 feet between the winter low and the spring high.

The water table rises sharply during the winter and early spring, especially when rainfall and run-off are heavy. The effects of direct recharge from run-off of Cucamonga Creek and other sources are evident within a few weeks. The effects of recharge are nullified during the pumping season, but following seasons of excessive rainfall, like 1915–1916 and 1921–1922, the recharge continues for more than a year, and results in a higher water table the second spring than the first spring after the winter of heavy precipitation.

Since percolation from direct run-off and rainfall is practically complete within a few weeks or months after the supply at the surface fails, some indirect source of underflow is believed to account for the long continued recharge.

The record of well No. D-707 * in the northwest corner of the basin is enlightening in this respect, for it is so situated that it could obtain underflow only from the northeast corner of Claremont Heights Basin at the mouth of San Antonio Canyon, or from Cucamonga Canyon. The channel cross-section of Cucamonga Canyon is too small where it enters the basin to supply a significant amount of underflow.

The water level in D-707, following the wet winter of 1926–1927, rose to a measured peak for the year of 1506.6 feet elevation, but the following April it rose to 1564.6 feet elevation. There is evidently a delayed recharge into the northwest corner of the basin. Unfortunately the record for this well is too short to show conditions following earlier years of excessive precipitation. The fluctuation for the short period in D-707 is similar to that of wells farther southeast in the central part of the basin for the same period, and therefore indicates that the delayed recharge enters the northwest corner of the basin. The water table at the mouth of San Antonio Canyon in the spring of 1928 stood at an elevation of about 2000 feet, and at about 1700 feet in wells southwest of D-707 in Claremont Heights Basin. It seems distinctly possible from the foregoing data that underflow passes east from the uppermost part of Claremont Heights Basin at the mouth of San Antonio Canyon into Cucamonga Basin. If this is true, then the northern end of the Chino Basin as shown on Plate E probably does not extend north to Cucamonga fault between Claremont Heights and Cucamonga Basin. There are not sufficient data available to permit a definite conclusion on this matter at present.

At all times there appears to be considerable underground waste out of Cucamonga Basin through the fault zone in the alluvium which forms the boundary. In January, 1933, there was more than three hundred feet difference in elevation of the water table on opposite sides of the fault, and a little less than 400 feet in 1904,† indicating that the difference in head has decreased less than 25 per cent. Probably the upper part of the fault zone is more permeable than the lower, and if so, the underflow may have decreased more than 25 per cent.

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* Division of Water Resources Bulletin 39, p. 350, 1932.

† Mendenhall, W. C., U. S. Geological Survey Water-Supply Paper 219, Pl. V, 1905.

A comparison of the water tables of 1904 and 1933 shows a net drop for this average rainfall period of 100 to about 200 feet. If the water table continues to lower, the underground waste should be reduced.

CHINO BASIN

Location and General Description.

Chino Basin lies beneath the broad alluvial plains in the central and western part of Upper Santa Ana Valley. Its south boundary is formed by Santa Ana River and the Jurupa Mountains, its east boundary by a supposed fault running northwesterly through Colton to the San Gabriel Mountains. The basin extends north to the San Gabriel Mountains and Cucamonga Basin, northwest to the Pomona Basin area and west to the Puente Hills. All boundaries of the basin except the southern boundary are determined largely or entirely by faults (Plate C).

Chino Basin is the main and largest basin in Upper Santa Ana Valley. Its surface area is 148,200 acres or about 232 square miles. Underflow from the Pomona Basin area, Cucamonga Basin, and the Rialto area of Rialto-Colton Basin passes directly through the alluvial fill into Chino Basin. From it water seeps into Santa Ana River. In addition to this, the ground waters of Riverside and Temescal basins rise along the river and add to its surface flow along the south margin of the basin. Below Riverside Narrows a part of the surface flow of the river at times percolates into Chino Basin.

Character and Depth of the Bedrock Floor.

The bedrock floor of Chino Basin, wherever encountered in wells, except in the southwest corner near the Puente Hills, has been found to be Basement Complex. In the southwest corner of the basin the alluvial fill is underlain by sandstones, conglomerates and shales, principally of the Puente formation, but, in part, of beds of post-Puente age (Plate D, section OP). Locally these beds contain some recoverable ground water.

The bedrock floor slopes toward the center of the basin from the north and south sides and is probably lowest in the vicinity of Ontario. Downfaulting of the basin around its margins has so depressed the floor that little is known of the contour of the deeper portions, but from the bedrock contours shown on Plate C, and scattered well points showing elevation of bedrock, the floor of the basin has the appearance of being a depressed drainage system, running westerly from the vicinity of Colton to Pomona. Probably before being depressed with respect to the Puente and San Jose Hills, this valley continued westerly through the hills approximately where San Jose Valley is now incised. The buried canyons of Riverside, Temescal and Pomona basins would be tributary canyons. The projection of these canyons toward the middle of the basin would indicate a maximum depth of between 1500 and 2000 feet of alluvial fill, giving elevations of 500 to 1000 feet below sea level, for the western part of the bedrock trunk valley near Ontario.

Faulting and deep alluvial fill obscure the details of this probable buried drainage system in the northern part of the basin, and in the basins to the east of Chino Basin.

Character of the Water-bearing Series.

The alluvial deposits of Chino Basin have been derived from all sides, and owing to these diverse sources and to the extensive area of the basin, there are wide variations in their character. It can be seen from Plate C that crystalline (Basement Complex) rocks surround the greater part of the basin and that all the high mountains from which the major part of the deposits have been derived are composed of crystalline rocks. Streams from the eastern San Gabriel Mountains, and Santa Ana River from the San Bernardino Mountains, have deposited most of the alluvial debris.

In the early stages of alluvial deposition, however, before the cones from San Gabriel mountain streams had pushed their way across the valley, alluvial deposits brought down from the Santa Ana Mountains and from the hills along the southern margin covered the southern and southwestern part of the basin. Well logs show these deposits to be characterized by red, yellow and brown residual clayey materials. The river probably lay to the north in the deep part of the valley, and if so the water table was low beneath the steep cones from the south, permitting extensive surface weathering during accumluation.

Similar conditions existed in the northern part of the basin and much clayey material accumulated there also. Deposition has been most continuous through the central part of the basin, and less residual clay has formed in this area. The alluvial cones from the north have gradually spread to the south, pushing the Santa Ana River toward the southern margin of the basin and overlapping the clayey alluvial deposits. In the process, the river has finally been practically pushed out of its valley in the eastern part of the basin where it now flows through the hills near Riverside. Consequently, toward the southern margin of the basin the relatively fine grained and little weathered deposits from the north, which overlap those from the south, thin to a surface veneer and disappear entirely in places north of the river in the southwest part of the basin. The map, Plate C, shows there a belt of Older alluvium of the southern cones, north of the river.

Well log averages for different parts of Chino Basin, when divided into four areas as shown in Table 9, show considerable similarity, but the deposits are predominantly finer in the southern part of the basin.

TABLE 9

COMPOSITION OF THE WATER-BEARING SERIES IN DIFFERENT PARTS OF CHINO BASIN

	Per cent		
	Clay	Sand	Gravel
Northwest area	54.4	2.3	43.3
Northeast area	30.1	4.7	65.2
Southwest area	65.1	6.1	28.8
Southeast area	59.3	12.3	28.4

This is probably due in part to the high percentage of weathered material in deposits to the south and the relatively fine character of the overlying beds from the north. The greatest amount of gravel is found in the northeast part of the basin where Lytle Creek has deposited the materials. The higher percentage of gravel through the central belt is not brought out in the above table because a part of it lies within each of the four divisions.

The coarsest gravels in Chino Basin lie along the northern margin, although there are also some rather coarse gravels in the deposits from the south. Boulders several feet in diameter are common in the deposits near the northern margin of the basin, and cobbles six inches in diameter are found in the gravels along the southern margin of the basin.

The gravels are finest in the vicinity of Chino and east to the Jurupa Mountains. The coarsest cobbles in this area are only a few

PLATE XX

Detail of Gravel bank on lower part of San Antonio Cone near Pomona.

inches in diameter. Toward the south the upper gravels (from the north) become finer, but the lower gravels (from the south and west) become coarser and also approach the surface.

The average maximum 10 per cent grade size of gravels was estimated to vary from 10 to 20 inches, at the northern margin of the basin, to $\frac{5}{8}$ to $1\frac{1}{4}$ inches in the vicinity of Chino, and to increase again to $1\frac{1}{4}$ to $2\frac{1}{2}$ inches at the southern margin, outside the Santa Ana River channel.

On this basis the specific yield assigned to unweathered gravels increases from 13 per cent in the northern part of the basin to 23 per cent a short distance southeast of Chino (Plate F). In the eastern part of the basin the highest specific yield is 17 per cent along the south margin of the basin.

Specific Yield and Storage Capacity.

In Chino Basin the storage capacity for a zone averaging 100 feet thick, from an average of 50 feet above the water table of January, 1933, to an average of 50 feet below that water table, was computed. Specific yield contours for this zone are shown on Plate E. The zone above the water table has a minimum thickness of five feet at the edge of the artesian area south of Chino and increases to 100 feet along the northern border of the basin east of Cucamonga Basin. The zone below the water table is similar, but starting from a minimum of five feet at a point within the artesian area in the southwest corner of the basin, it increases to 90 feet along the north border in the eastern part of the basin.

The total computed storage capacity for the theoretical zone of fluctuation averaging 100 feet thick is 1,119,000 acre feet; 48 per cent of this is below the water table and 52 per cent above. The smaller capacity of the lower part of the zone is due to lower specific yields in the Water-bearing series.

The specific yield contours for the entire zone (Plate E), show a belt of high yield running east-west through the central part of the basin. Yields of 10 to 15 per cent occur throughout this belt. They decrease toward the north, reaching a minimum of about five per cent at the north margin of the basin. The specific yield decreases also toward the south and southwest from the center, being from four to six per cent along the southern margin, and as low as three per cent at the margin southwest of Chino. In Santa Ana River channel the yield rises to 12 and 13 per cent.

Ground Water in Chino Basin.

Underflow from adjacent basins and percolation of run-off and rainfall upon the valley floor are the principal sources of ground water in Chino Basin. The ground water moves south in the western part of the basin, and west and southwest in the eastern part, converging toward the artesian area and Santa Ana River in the southwest corner of the basin (Plate E).

Origin and Nature of the Artesian Area. Originally there was a large triangular artesian area along the southwest margin of the basin, extending southeasterly from about two miles southeast of Pomona to within two or three miles of Santa Ana River.*

At present only a few scattered wells south of Chino yield flowing water, and these only during part of the year. There is considerable natural waste, however, in the form of evaporation, transpiration and rising water in the ravines that cut into the southern part of the artesian * area and drain it.

Structurally the artesian area is simple. It is flanked on the southwest by the Chino fault and Puente Hills which form an impervious barrier to the movement of ground water in the basin. The artesian area lies along the southern margin of San Antonio alluvial cone where the gravel beds, open toward the north, interfinger with the less

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* Mendenhall, W. C., *op. cit.*, Plate I.

* The term artesian is applied here to the water which rises under pressure to the surface in wells. Artesian area is applied to a pressure area in which wells have in the past flowed, or do flow at present.

pervious clayey alluvial material from the south and southwest. This clayey alluvium, which acts as a partial barrier, crops out along the southern rim of the artesian area as low, scarcely perceptible hills, surrounded by Recent alluvium (Plate C).

The ground water, moving south and southwest through the gravels of San Antonio cone into the artesian area, is confined by the thinning of the gravel beds, and by the rising surface of the underlying clayey alluvium. Pressure is thus built up and when the basin is full, wells tapping these gravels produce artesian water. The ground water is forced under pressure south through the clayey alluvium, but the pressure is relieved between the artesian area and Santa Ana River by surface drainage. The ground waters rise to the surface in the ravines that cut back into the higher alluvial surface to the north from the lower level of Santa Ana River flood plain.

There is no surface or underground evidence of a fault terminating the artesian basin on the south, and it seems reasonable, therefore, to attribute the artesian pressure solely to the natural conditions outlined above.

There are no structural barriers within Chino Basin that have an important effect upon movement of the ground water. The slight changes of gradient that are apparent from water table contours on Plate E are probably due to differences in the amount of clayey material in different parts of the basin.

Fluctuation of Water Levels and Recharge. The storage capacity of Chino Basin is very large compared to annual recharge or withdrawals, consequently the annual fluctuation of static levels in wells is small. The record of well No. D-743r,* and other nearby wells in the western part of the basin, shows annual static level fluctuations have been generally less than five feet. These have increased somewhat in recent years, however, and now sometimes exceed five feet. Fluctuation of the static level in well No. D-1065,† and nearby wells in the southeastern part of the basin, is less than five feet annually. Wells to the north and west also show annual static level fluctuations of only a few feet.

Owing to the relatively small direct recharge from percolation of run-off and rainfall, and to the wide distribution of the percolating areas, the recharge even in years of heavy precipitation does not have a sharp effect on the water table. The long period rise and fall of the water table seems to be governed to a large extent by the amount of underflow from adjacent basins. In the western part of the basin the record of D-743r and others show a noticeable rise beginning in 1916 and culminating at the end of 1917. The water level did not begin to decline until 1920, however. The height of the water table in this area appears from this sort of fluctuation to be dependent largely upon underflow from Pomona Basin. A general rise began about two years after the heavy precipitation of the winter of 1913–1914, and the water table remained high for several years, then as the underflow from Pomona Basin began to fail, it started the decline in the western part of Chino Basin which has continued to the present. This condition exists also throughout the northern and eastern part

* Division of Water Resources Bulletin 39, p. 360, 1932.
† Division of Water Resources Bulletin 39, p. 416, and Bulletin 39-A, p. 66.

of the basin where underflow from both Cucamonga Basin and the Rialto area have partially failed.

There has been a net decline of 50 to 80 feet in the northwestern part of the basin from 1904 to January, 1933, probably a little less in the northern part east of Cucamonga Basin. Along the northeast margin, from 60 to 70 feet at the northwest end to about 10 feet at the southeast end. The declines have been less near the south margin and near the artesian area. It is interesting to note that in the region southwest of Fontana, north and west of the Jurupa Mountains, the water table has risen a few feet during the same period. Probably this rise is due to an increase in return irrigation water from the Fontana and Bloomington areas. A large part of the water used for irrigation in this part of Chino Basin is imported from Lytle Creek, Lytle Creek Basin and the Rialto area.

From the above analysis it seems reasonable to conclude that the decline of the water table in Chino Basin during the average rainfall period from 1904–1933 is due both to an increased pumping draft and a decrease in underflow from adjacent basins. At present, there is still a ground water surplus that rises to the surface in the southwest part of the basin. If the increased draft and decreased inflow continue to exceed the decrease in waste from the lower part of the basin, there will be further depletion of storage, and the water table will decline until the decrease of natural waste balances the other two factors. Should there be further depletion in the basins whose underflow feeds Chino Basin during an average rainfall period, or should the pumping draft increase within the basin, the surplus at the lower end of the basin may disappear.

CHAPTER VII

COASTAL PLAIN BASINS

West (31)*
  Northern Area (31a)
  Southern Area (31b)
Hollywood (32)
Central (33)
  Los Angeles River Area (33a)
  San Gabriel River Area (33b)
  Santa Ana River Area (33c)
  Irvine Area (33d)
La Habra (34)
Yorba Linda (35)
Los Angeles Narrows (36)
Santa Ana Narrows (37)

The Coastal Plain area of Los Angeles and Orange counties contains three major structural ground water basins, each of which is further subdivided. These basins are: (1) West Basin, (2) Central Basin (including Hollywood Basin), and (3) the La Habra Basin area.

West Basin lies south of the Santa Monica Mountains and west of the Beverly-Newport uplift. Central Basin lies east of the Beverly-Newport uplift, south of the Repetto Hills and Santa Fe Springs-Coyote uplift, west of the Santa Ana Mountains and north and northeast of San Joaquin Hills. The La Habra Basin area lies between the Puente Hills and the Santa Fe Springs-Coyote uplift, extending easterly from San Gabriel River to Santa Ana River.

WEST BASIN

Location and General Description.

The West Basin of the Coastal Plain has a surface area of 120,500 acres or approximately 188 square miles. Its length from northwest to southeast is 25 miles and its average width about seven miles.

The surface is a dissected and slightly deformed plain which was formerly a sea floor. It is modified also by local accumulations of alluvium and sand dune deposits. The dissected plain stands 50 to 150 feet above sea level except along the northern margin where old alluvial cones from the Santa Monica Mountains are deposited upon it. The broad alluvial valley of Ballona Creek and its branches from the north are incised to the depth of more than 100 feet into the old marine surface and lie but a few feet above sea level.

The uplifted marine floor, the remnants of which form a large part of the basin surface, is folded up over the Beverly-Newport uplift, and is the surface along the greater part of its length. During late Pleistocene time, this surface stood 100 to 200 or more feet above its present level. The various streams draining from the interior cut canyons through the uplifted surface to the lowered base level. The Beverly-

* Numbers in parentheses are index numbers of basins as shown on Plate E in pocket.

Newport uplift was cut through in six places, beginning on the north with Ballona Gap near Culver City and ending at the south with Santa Ana Gap (Plate B). Sepulveda Creek, entering Ballona Creek (which runs through the valley east of Venice) from the Santa Monica Mountains, has deeply dissected the old plain between the mountains and Ballona Creek.

The late Pleistocene emergence has been followed by a period of general submergence, or more probably by a period of rising sea level. that accompanied melting of the glaciers at the end of the last glacial period. Since reaching the present position, the deeper canyons have been filled with clays, sands and gravels, in part continental, but near the coast principally estuarine or truly marine.

The water-bearing deposits of West Basin consist, first, of the undeformed and slightly deformed marine beds of Palos Verdes age which underlie the uplifted sea floor, and second, the later marine deposits and their correlative continental deposits which fill the channels cut through the Palos Verdes beds and cover the depressed areas. Locally beneath the unconsolidated Palos Verdes beds, folded beds. probably of the San Pedro series, contain water-bearing sands and gravels.

Character and Depth of the Basin Floor.

The unconsolidated marine and continental deposits of Palos Verdes age and older water-bearing marine beds are underlain by a thick series of marine clays, silts and fine sands of Lower Pleistocene age. The youngest of these beds probably belong to the San Pedro series.

The water-bearing beds are comparatively thin in the vicinity of the coast from Redondo north to the Santa Monica Mountains, where the depth to the Lower Pleistocene silt series varies from 200 to about 400 feet. Similar conditions exist along the Beverly-Newport uplift, where the water-bearing beds have a thickness generally between 200 and 500 feet. In the Baldwin Hills, however, the silt crops out at the surface.

Between the Beverly-Newport uplift and the high area near the coast, the old marine surface has been depressed. This synclinal area. almost imperceptible near Ballona Creek at the surface, broadens and deepens toward the southeast. In the vicinity of Gardena, alluvial and lagoonal beds 100 feet or more thick have been deposited above the Palos Verdes marine beds exposed at the surface elsewhere. The water-bearing series along the axis of this syncline increases from a thickness of about 600 feet to a probable maximum of more than 1000 feet beneath the Los Angeles River in the southeast part of the basin.

North of Ballona Creek comparatively little is known about the thickness of water-bearing materials. Widely scattered wells drilled through the Water-bearing series into silts and clays show depths ranging from about 200 feet to a little more than 600 feet. The silts approach the surface toward the Santa Monica Mountains. A small fault, about one mile northwest of Sawtelle, brings the silts to the surface. They are exposed beneath about 100 feet of alluvial gravels in ravines along the coast northwest of Santa Monica. Oil well logs indicate that the base of the gravels is about 200 feet beneath the surface along the axis of the Playa del Rey anticline at Venice.

In the area from Venice and Santa Monica to the Beverly-Newport uplift, few water wells are more than 300 feet deep, but scattered wildcat oil wells indicate probable depths of 300 to 700 feet for the Water-bearing series in this area..

Character of the Water-bearing Series.

The water-bearing series of West Basin consists of several hundred feet of marine gravels, sands and clays of the Palos Verdes and possibly a part of the San Pedro series, overlain in places by estuarine lagoonal and alluvial deposits of both Palos Verdes and Recent age. These later deposits attain a maximum thickness between Santa Monica and Sawtelle Boulevard, of about 300 feet, where alluvial gravels from the Santa Monica Mountains have filled submerged canyons cut into the marine Palos Verdes beds.

North of Ballona Creek plain, the alluvial deposits have been derived almost entirely from the Santa Monica Mountains. Well logs averaged together in this area show 54 per cent of clayey material, 18 per cent of sand, and 28 per cent of gravel in the alluvial deposits. A large part of the clay is due to alteration of gravels through weathering.

In this same area the marine deposits contain a much smaller percentage of clay and a much larger percentage of sand, the average for these deposits being: Clay, 29 per cent; sand, 46 per cent; and gravel, 25 per cent. These deposits have not been appreciably affected by weathering except at the surface.

South of Ballona Creek the alluvial deposits form a comparatively shallow layer covering the depressed marine beds in the area lying southwest of the Beverly-Newport uplift. Except at their extreme southeast end where the Los Angeles River has contributed material, these alluvial deposits have been derived locally from rewashing of the surrounding slightly higher areas of marine sediments. Consequently, the alluvium is in the main, fine grained, and in the central part contains some lagoonal beds. Well log averages indicate the nature of these superficial deposits. They show 65 per cent of clay, 21 per cent of sand, and only 14 per cent of gravel. The clays are not entirely depositional, for yellow clays are commonly reported in well logs. These are probably derived in part from sands through weathering.

The marine deposits of the water-bearing series south of Ballona Creek are similar but slightly finer than those to the north, probably because they were not fed by steep gradient streams from nearby mountains as were those near the south base of Santa Monica Mountains.

Well log averages of these deposits show: Clay, 34 per cent; sand, 46 per cent; and gravel, 20 per cent.

It can be seen from the above data that in the marine deposits the sand percentage is more than twice, and the clay percentage only about half that in the alluvial deposits, while the differences in gravel percentages are of less magnitude. It seems probable from this that the marine deposits were finer than the alluvial deposits when originally laid down, but that secondary clays due to weathering and soil formation during accumulation of the alluvial deposits, have increased the clay percentage at the expense of the sand and gravel content in the alluvium.

The superficial clayey deposits that have accumulated in the synclinal area extending southeasterly from Inglewood to Long Beach, form a relatively impervious cap above the marine beds. The downward percolation of surface waters from rainfall and other sources is very slow through this clayey cap, and consequently water is perched upon the clay strata, forming essentially a saturated zone extending downward from within a few feet of the surface to the main water body. The upper surface of this water, or the water table, fluctuates very little from year to year and therefore it is thought that storage changes within this area of "perched" water is negligible. The ground water in the marine series is confined by the overlying clay beds, and is therefore under pressure except around the margins where the tight material disappears or lies above the normal water table.

In the synclinal area the water levels of wells which produce from the marine series are pressure levels, and stand below the surface of the saturated zone. Their fluctuations therefore do not indicate changes of storage within the pressure area. Shallow wells produce small quantities of water from occasional sands and gravels in the alluvium, but owing to the tightness of the materials, levels in these wells probably represent conditions only in the immediate vicinities of the respective wells.

The alluvium thins out and disappears around the margins of the synclinal area, and the saturated alluvium probably becomes perched above unsaturated marine beds toward its margins, which drain into the ocean or into wells. The limits, therefore, of the area in which no storage change takes place, are very uncertain and probably shift considerably as the water levels in the marine beds rise and fall. The area of the zone of no change increases with a rising water table and decreases with a falling water table. On the map, Plate E in pocket, a line is drawn to indicate the approximate limit of the area in which it is thought that practically no storage change occurs under conditions as they exist today. This line is a preliminary estimate and further work may necessitate some changes.

Outside the area of perched water the deeper wells in the marine series fluctuate in a manner that indicates that ground water there is under some pressure. This is no doubt due to clays interbedded with the sands and gravels. Perched water is not present in any considerable areas outside the synclinal area considered above, however, and it is thought that if erratic and sharp water level fluctuations are disregarded, the levels that prevail during periods when pumping is at a minimum probably closely represent the water table. Orderly fluctuations in such levels represent changes of storage.

Specific Yield and Storage Capacity.

In West Basin the storage capacity for a zone from 50 feet below the water table of January, 1933, to an average height of 50 feet above the same water table was computed for the northern area. This zone was varied from a maximum of 100 feet above and 100 feet below the water table along the north and east margins of the area of storage change to a minimum of zero along the sea coast. The total estimated storage change for this 100 foot zone in the northern area is 288,000 acre feet. For the southern area, the zone computed averages 25 feet above and 25 feet below the water table. The storage capacity of this 50 foot zone is estimated to be 402,000 acre feet. The small space above the water table in this area limits the practical storage zone to about the 25 foot figure, and since the water table can not be safely drawn down below sea level along the coast, an average 25 foot zone below the water table probably approximates the maximum storage available.

The specific yields for storage capacity zones were contoured and shown on Plate E. The specific yield varies from a high of 20 and 22 per cent along the coast where the material is principally sand, to six per cent along the margin of the pressure area. The yield decreases to about four per cent along the margin of the Santa Monica Mountains where there is a high percentage of residual clay in the deposits.

Ground Water in West Basin.

The ground water in West Basin originates principally from three sources: (1) by percolation of run-off from streams draining the adjacent southern slopes of the Santa Monica Mountains; (2) by underflow through gaps and other partly permeable portions of the Beverly-Newport uplift, from Central Basin; and (3) by direct percolation of rainfall upon the basin floor.

The influence of the first source is felt only in the northern area where the water table slopes southerly from the mountain-front toward the low flat-lying Ballona Valley east of Venice. The influence of ground water which percolates across the Beverly-Newport uplift is most pronounced near the north side of the surface gap of Ballona Creek near Culver City, and at the Dominguez Gap, but is evident elsewhere also along the uplift. In 1905, according to the hydrologic maps of Mendenhall,* the water table sloped in a general way from the Santa Monica Mountains and Beverly-Newport uplift toward the ocean into which the underground surplus wasted.

At present conditions are much different, as indicated by the ground water contours for January, 1933, Plate E, in pocket. These contours show that the water table slopes toward the central part of the basin from all sides. It stands from five to 20 feet below sea level there, the lowest portion lying northeast of San Pedro Hills.

Well records throughout the area show a gradual decline from 1905 to the present. During the wet period from 1914 to 1917, and for a year or two following, the decline was checked and levels rose a little in some places, but during the dry period that has followed, the decline has been accelerated and the few wet years during this period have not had noticeable effect. The underground supply available to the basin is dependent upon the height of water levels in Central Basin along the Beverly-Newport uplift, and consequently the gradual decline of

* Mendenhall, W. C., U. S. Geological Survey Water-Supply Paper 139, Pls. V and VI, 1905.

pressure in the underground strata there has greatly reduced the available supply.

The storage capacity in this basin is very large compared to annual supply and demand. With a gradually diminishing supply, the water table has slowly receded. The increased supply in wet years is scarcely noticeable because of the enormous storage capacity.

It is interesting to note that the ground water contours on Plate E show a gradient downward from the sea coast toward the interior of the basin. This condition indicates that the ground water is moving inward, at least in the deeper strata, from beneath the ocean along the coast from Santa Monica to Redondo, and from San Pedro to Seal Beach. This condition has existed for several years, and since actual encroachment of ocean water is evident in limited areas only,* it seems probable that the fresh ground water body normally extends out beneath the ocean floor, where it is sealed off from the overlying ocean waters by relatively impervious beds. At one time when the land surface stood higher, the water table along the coast probably stood well above sea level and the fresh water body probably extended a considerable distance out under the present ocean floor. It evidently still so extends, but as the water table declines it seems probable that this fresh water body is being replaced by salt water just as edge-water encroaches upon the productive zones in an oil field as the oil is removed. Eventually, since there appear to be no effective barriers along this coast, with a continuation of the present trend, salt water might be expected to encroach upon the pumping area along the entire ocean front and gradually reduce the area from which fresh water can be produced. The quantity of ground water removed from beneath the ocean and replaced by salt water is unknown.

HOLLYWOOD BASIN †

Location and General Description.

Hollywood Basin lies at the northwest end of the Central Coastal Plain between Central Basin and Santa Monica Mountains. It is a narrow basin about two miles wide and six miles long, parallel to the south front of the mountains. The surface area is 9450 acres or a little less than 15 square miles.

The basin lies in a narrow synclinal area, separated for the most part from Central Basin to the south by the anticlinal and probably faulted east-west structure of the Salt Lake oil field (a short distance north of Wilshire Boulevard, Plate B) which brings shales up to within 100 feet of the surface. The synclinal area to the north is connected around the west end of the oil field structure with Central Basin (Plate B, in pocket). The south boundary is extended westerly across this area to the Beverly-Newport uplift which forms the western boundary. The eastern boundary is formed by the hills of Puente shale in the northern part of Los Angeles.

* Scofield, Carl S., South Coastal Basin Investigation, Bulletin 40, pp. 86-89, 1933.

† Structure of this basin was worked out by J. C. Kimble, Geologist on the Division staff.

Character and Depth of the Bedrock Floor.

The water-bearing deposits of Hollywood Basin are underlain in the eastern part by Puente shales similar to those that crop out in the vicinity. Toward the west, shales and silts of the Fernando formation form the floor of the basin.

From the depth of about 100 feet along the greater part of the southern boundary, the basin floor drops toward the north and west to the depth of 700 feet or more. The floor rises steeply from the deep axis to the north edge (Plate B, in pocket).

Character of the Water-bearing Series.

The deeper of the water-bearing deposits in this basin is marine Pleistocene beds. These beds are good producers of water. The upper several hundred feet of deposits are principally, if not entirely, continental throughout the deeper portion of the basin. The continental beds appear to be from 300 to 500 feet thick. In the western part of the basin, at least, there is a zone 100 feet thick or so in which continental and marine beds interfinger.

The well log averages show principally alluvial deposits. These beds have been deposited by streams draining the south front of Santa Monica Mountains. An analysis of the well log averages shows 66.4 per cent clay, 18.3 per cent sand and 15.3 per cent gravel in the alluvial deposits.

On the basis of the maximum 10 per cent grade size of gravel materials, estimated from well logs, the specific yield assigned to unweathered gravel varies from 16 per cent along the northern margin of the basin to 18 per cent at the southern.

Specific Yield and Storage Capacity.

The storage capacity was computed for a zone 100 feet thick, uniformly 50 feet above and 50 feet below the January, 1933, water table. The storage capacity of this zone is estimated at 38,000 acre feet, or 380 acre feet per foot average rise or fall of the water table. The specific yield contours for this zone (Plate E, in pocket) show a variation from about four per cent along the northern border to six per cent in the southwest corner of the basin.

Ground Water in Hollywood Basin.

Ground water in Hollywood Basin is derived from percolation of run-off from the adjacent southern slopes of the Santa Monica Mountains and from percolation of rainfall upon the basin surface.

The water table slopes southerly from the mountains, rising to the surface toward the south, where the bedrock high of the Salt Lake oil field just north of Wilshire Boulevard (at the Brea Pits) forms a barrier. Formerly, according to Mendenhall,* two artesian areas existed, one in the southwest corner of the basin where the topography is low, and the other near the southeast margin of the basin. Continuous water level records are not available in this area, but scattered

* Mendenhall, W. C., U. S. Geological Survey Water-Supply Paper 139, Pl. VI, 1905.

records indicate that water levels have declined from a few feet to 50 feet in different parts of the basin since 1905.

CENTRAL BASIN

Location and General Description.

The Central Basin of the Coastal Plain extends southeasterly from Hollywood Basin near the south front of the Santa Monica Mountains to the Irvine area and is bounded along the southwest by the Beverly-Newport uplift. On the northeast it is bounded by the Santa Fe Springs-Coyote uplift east of the San Gabriel River, and by the Repetto Hills and hills of the Los Angeles area to the west. The basin has a smooth undeformed surface sloping gently southwest, comprising the compound alluvial cone produced by the three rivers and the smaller streams that discharge onto the plain. It is undissected except around the margins. The surface area of the basin is 374,400 acres or 586 square miles.

The basin is a structural unit, there being no important obstructions to the movement of ground water through it. However, because of the local nature of problems of supply and demand and for convenience of discussion, the basin is divided into four parts, as follows:

(1) Los Angeles River area, extending from the northwest limit of the basin southeasterly to the Los Angeles River.
(2) San Gabriel River area, extending from the Los Angeles River easterly to the Orange County Line.
(3) Santa Ana River area, extending southeasterly from the Orange County Line to an appropriate line running through Orange and Santa Ana.
(4) The Irvine area, occupying the arm of the basin which lies southeast of Santa Ana.

These four areas denote in a general way the regions of influence of the ground waters of Los Angeles, San Gabriel and Santa Ana rivers, and local streams from the hills around Irvine. No structural subdivisions exist between these, and the areas of influence change according to local supply and demand.

Character and Depth of the Bedrock Floor.

The base of the Water-bearing series is not definite in all places. The lower Pleistocene beds generally are nonwater-bearing throughout the western part of the basin. Along a large part of the northeastern margin, and locally along the Beverly-Newport uplift, the Lower Pleistocene beds of the Fernando formation are water-bearing (Plate B).

The water-bearing formations are underlain by thick series of Lower Pleistocene and Pliocene (Fernando) sandy shale and siltstone with sand and conglomerate lenses. These nonwater-bearing beds are generally conformable in the central parts of the basin with the overlying water-bearing beds. The lower limits of the water-bearing materials are irregular and not at the same stratigraphic horizon throughout the basin.

The depth increases from zero or a few hundred feet around the margins to 2000 or 3000 feet maximum in the eastern part near the mouth of Santa Ana Canyon, where folded Lower Pleistocene water-bearing conglomerates underlie the alluvium. The water-bearing beds probably have a depth of about 1500 to 2000 feet throughout the central part of the basin. The depth diminishes rapidly near the Beverly-Newport uplift and here varies from zero to 500 feet along the axis of the uplift (see geologic sections across Coastal Plain on Plate D).

Nature of the Beverly-Newport Uplift.

The Beverly-Newport uplift, which separates West Basin from Central Basin is not a simple structure. Its surface expression as indicated on Plate B, is a series of discontinuous faults and folds extending southeasterly from the Santa Monica Mountains to Newport Beach.

Although a series of domes and saddles occur along the uplift, the structure as a whole is anticlinal with respect to the basins on either side. The structural descent is much sharper toward the northeast into Central Basin than toward the southwest into West Basin.

At two points along the uplift, the Fernando silts of the Nonwater-bearing series are exposed at the surface. They crop out along the northern side of the Baldwin Hills near Culver City, and in an area too small to be shown on the geologic map, overlying Puente shale in the sea cliff northeast of Newport Beach. Elsewhere along the axis of the uplift 200 to more than 500 feet of water-bearing deposits overlie the silts.

There are six broad surface gaps in the uplift through which drainage from the Central Plain area passes. These are marked by belts of Recent alluvium crossing the uplift (Plate B).

Some of the surface gaps lie above structural saddles in the uplift, but this is not true of others. In all these gaps, however, there is Recent fill to the depth of 100 feet or more, which has been affected less by faulting than the older water-bearing deposits on either side and below.

At Ballona Gap near Culver City, there is a structural saddle between the Inglewood oil field anticline on the south side of the gap and the Beverly Hills oil field high, just south of Wilshire Boulevard (Plate B). The top of the silts is about at sea level or possibly 100 feet above, in the Beverly Hills field, and crops out at the surface south of the gap at the edge of the Baldwin Hills. The greatest depth to silts along the uplift axis in the saddle is not known, but from well logs nearby it is estimated to be 300 to 400 feet below sea level. The lowest part of the saddle is probably at the north edge of the surface gap.

The Dominguez Gap overlies a structural saddle between the high structures of Dominguez oil field to the northwest and Signal Hill oil field to the southeast. The greatest depth of pervious fill along the axis in this gap is probably about 500 feet below sea level, and decreases to the neighborhood of 300 feet on either side.

The Seal Beach surface gap lies above the Seal Beach anticline and here the minimum depth below sea level to the Nonwater-bearing series is probably less than 200 feet.

Between the Seal Beach anticline and the Huntington Beach anticlinal area, there appears to be a broad saddle in the uplift. Scattered well logs indicate thicknesses of water-bearing materials of 500 feet or more. Two surface gaps cross this saddle, the more northerly probably lies above the low part of the saddle.

Santa Ana surface gap, through which Santa Ana River flows, overlies in part a structural saddle, but faulting has complicated conditions. The top of the silts varies in depth from about 250 feet below sea level near the south edge of the Huntington Beach mesa, to more than 600 feet in the center of the gap near the seacoast. The silt surface rises again toward the south and is exposed at the surface in the sea cliff at the south margin of the gap.

Since there are several hundred feet of gently folded water-bearing deposits overlying the Beverly-Newport uplift throughout most of its length, the faults which cut these deposits form the principal barriers to the movement of ground water across the uplift.

The Inglewood fault zone, which coincides with the uplift northwest of Signal Hill, is a series of short faults with an en echelon arrangement. They strike more nearly north and south than the uplift. The faults are of small displacement. They displace the surface of the marine series in different places from a few feet to nearly 100 feet in the Baldwin Hills, but do not displace the Recent alluvium in either Ballona or Dominguez gaps. The throw measured on one of these faults which cuts through the Inglewood oil field in Baldwin Hills, was 350 to 400 feet, the east side having been elevated.

Southeast of Signal Hill the faulting becomes more continuous and from Seal Beach almost to Huntington Beach is marked by only one line at the surface. It may well be that the fault beginning near the southeast end of Signal Hill and running southeasterly, is continuous to Newport Beach or beyond (Plate B). At only one point is there good evidence that this fault cuts Recent fill. In the surface gap southeast of Seal Beach there is a mound on the tidelands along the projected line of the fault, which is probably a remnant of deformation in the Recent fill.

Character of the Water-bearing Series.

The water-bearing materials are made up of two unconformable series (Upper Pleistocene alluvial and marine beds, and Lower Pleistocene marine conglomerates) around the margins, but these two series are probably conformable throughout the central part of the basin. The Upper Pleistocene beds are undeformed or slightly deformed continental and marine series of clays, sands and gravels, varying from zero around the margins to a maximum depth of about 1500 feet in the central part of the basin. The Lower Pleistocene deposits are principally marine but contain continental beds in the eastern portion. They have a maximum thickness of about 1000 to 1500 feet. In the eastern part of the basin from Placentia south to Tustin, this series contains coarse conglomerates. Toward the west and northwest the conglomerates become finer and finally disappear, being replaced by sandy silts and clays. Along the Beverly-Newport uplift the upper portion of the Lower Pleistocene beds at places contains lenses of water-bearing gravels. These are exposed at the surface beneath the marine terrace near the mouth of Santa Ana River.

Although the Lower Pleistocene gravels are important sources of water supply, they are too deep to be in the zone of storage change except locally along the eastern margin of the basin. Consequently, distribution of the gravels in the Upper Pleistocene beds are of greater importance to the consideration of storage capacity. The marine beds of the upper series, exposed at the surface along a large part of the Beverly-Newport uplift, are covered by alluvial deposits of increasing depth toward the northeast. In the northeastern half of Central Basin these marine deposits are generally covered by 500 to 1000 feet of alluvium (Plate D, sections GH, JK and LM) and are below the zone of storage change. The character of the overlying alluvial material is of primary importance in estimating storage capacities and changes, for the zone of probable storage change lies principally within these materials.

PLATE XXI

Tilted Older alluvium at edge of Coastal Plain near Montebello.

The Upper Pleistocene beds are the deposits of Los Angeles, San Gabriel and Santa Ana rivers, Santiago Creek and local streams which drain the foothills of the Santa Ana Mountains and San Joaquin Hills. The marine beds which predominate throughout the southwest half of the basin are probably derived from the same sources, by reworking and deposition under water.

The size distribution in gravels of the Central Basin can not be detected from observation of the surface materials on the Coastal Plain, since sands, silts and soils cover the surface of the flood plain. The size distribution in Upper Pleistocene gravels as reported in well logs corresponds in a general way to the location of the present sources; that is, the coarsest gravels occur along the north and northeast margins of the basins and the finest are found toward the southwest. The coarsest gravels occur at the head of the Santa Ana and Santiago cones where boulders up to twelve inches or more in diameter occur in the coarse gravel beds.

Cobbles of the coarse gravel beds in the San Gabriel and Los Angeles River cones on the Coastal Plain are three to six inches in diameter. Gravels comparable in coarseness to those at the head of lower Santa Ana Cone are found in places along the base of the hills between the major cones, and these become finer rapidly toward the central part of the basin and within about a mile of the hills are finer than nearby gravels from the large streams.

Southwesterly across the basin the gravels gradually diminish in grade size. The average size of the largest cobbles reported in wells within two or three miles of the Beverly-Newport uplift is two to three inches in diameter. Gravels near the heads of the cones are poorly sorted with poorly rounded cobbles. The beds are often 20 feet or more thick. Along the southwestern side of the basin the gravels are better sorted, well-rounded pebbles and cobbles, and gravel beds only a few feet thick alternate with sand and clay beds.

Specific yield of unweathered gravels of the Central Basin, on the basis of the maximum 10 per cent grade size of gravel estimated from well log data, varies from 14 and 15 per cent at the head of lower Santa Ana River and Santiago Creek cones, and 19 per cent at the heads of Los Angeles and San Gabriel River cones, to 23 per cent along the southwest margin of the basin southeast of the Los Angeles River.

In the Central Basin well logs show the highest percentage of gravel and lowest percentage of clay to be in the vicinity of the heads of Los Angeles, San Gabriel and Santa Ana cones. The greatest amount of clay is found in the northeast part of the basin between these three rivers, in the Irvine area, and in the alluvial deposits of the southwestern (coastal) portion of the basin.

Table 10 shows the distribution of clay, sand and gravel in the alluvial deposits throughout the basin, and in the marine deposits of the southwestern or coastal portion of it. The marine deposits are too deep in the northeastern part of the basin to be encountered by sufficient wells to give reliable averages in most of the district.

Both the marine and alluvial deposits in the coastal region and the alluvial deposits in the Norwalk area appear to represent a normal depositional series from coarse to fine materials practically unaffected by weathering, with the fine material predominating. Weathering has had no opportunity to alter the marine beds, and due to the low slopes and high water table where the alluvial beds have accumulated, very little alteration by weathering of these deposits has occurred. The clays were deposited in their present form and are generally blue or gray in color. The sand content in these deposits is relatively high, generally being higher than that of gravel.

In contrast to the coastal region, the Irvine and Santiago cones show a high percentage of clay but less sand than gravel. The deposits of San Gabriel and Santa Ana cones show a similar but less extreme relationship. It seems probable that in these areas of steeper cones, the original deposits were principally gravel and sand, but due to weathering permitted by a lower water table and intermittent periods of dissection much of the material has been altered to clay. The clays

TABLE 10

COMPOSITION OF THE WATER-BEARING SERIES IN DIFFERENT PARTS OF CENTRAL BASIN

District	Upper Los Angeles River cone	Upper San Gabriel River cone	Upper Santa Ana River cone	Montebello (between L. A. & S. G. river cones)	Norwalk (between S. G. & S. A. river cones)	Santiago Creek	Irvine area	Coastal area			
								Northwest		Southeast	
Origin	Alluvial	Alluvial	Alluvial	Alluvial	Alluvial	Alluvial	Alluvial	Alluvial	Marine	Alluvial	Marine
Clay	61.4	45.7	53.7	62.7	68.2	77.8	83.0	70.2	49.0	60.0	54.0
Sand	19.5	23.3	20.1	10.4	19.5	7.8	7.0	20.5	33.8	23.9	22.2
Gravel	19.1	31.0	26.2	26.9	12.3	14.4	10.0	9.3	17.2	16.1	23.8

are characteristically yellowish or reddish-brown and gritty. The gravels are often decomposed and clayey. Well logs indicate that the clays of Los Angeles River Cone are a mixture of depositional blue and gray clays and clays that have originated by weathering.

Pressure Areas and Areas of Storage Change.

The Central Basin is divisible into two areas according to the nature of movement of its ground water. The one is the area of intake or region in which there is a relatively unrestricted water table. It is in this area that changes of storage occur. The other is the area in which the ground water is confined beneath extensive clay beds which create artesian pressure. In this area the zone of saturation ordinarily extends practically to the surface and is relatively constant throughout the year. Therefore, there is no appreciable storage change. The pressure area or area of no storage change covers the southwestern two-thirds of the basin and extends easterly across the basin in the vicinity of the Los Angeles-Orange County line (Norwalk district). The limits of this pressure area are shown on Plate E, in the pocket. In this region clays have been formed by deposition on the flood plains and upon the ocean or bay floors, consequently they form impervious layers of considerable lateral extent, interbedded with water-bearing gravels and sands. They confine the water-bearing beds in such a manner that free percolation of water from one bed to another is restricted, and consequently artesian pressure is built up by the movement of ground water from the catchment area toward the ocean. This area of no storage change coincides roughly with the area in which perched water lies generally within 10 feet of the surface. The perched water is due to percolation of irrigation water and rainfall, and is sustained by the uppermost clay beds which confine the deeper waters. Since there is no great difference in the elevation of the perched water table and the piezometric level of the water of deeper strata, the entire depth below the perched water table is saturated at all times and the perched water keeps a relatively constant upper level of the zone of saturation. Downward leakage from this zone replenishes the lower strata when the levels in these strata are less than the perched water table. When levels in the lower strata are higher than the perched water table the leakage is upward and the perched water is supplied in part by this leakage.

Immediate and sharp water level fluctuations occur in wells within the pressure area in response to changes in the pumping draft. Such fluctuations are merely pressure effects and do not indicate storage changes.

The upper portions of the three river cones, Santiago cone and a part of the Irvine area, form the areas of intake for the Central Basin and are the areas in which the water table fluctuations produce changes of storage. Although there is a higher percentage of clay present in some of these areas than in the pressure area, the origin of these clays is principally through weathering and consequently they do not occur in regular confining layers. Water is somewhat restricted in the gravels and is under pressure where there is a high content of clay, but changes of pressure actually cause the water table to rise and fall although there is some lag, by forcing the water upward through interconnected gravels or allowing it to move downward. Thus downward percolating waters from the surface are not perched at a relatively constant level, but leak through the coarser material to the water table.

Specific Yield and Storage Capacity in the Intake Areas.

Specific yield values and storage capacity for a zone 100 feet thick, 50 feet above and 50 feet below the water table of January, 1933, were computed from specific yield data worked out from well logs. Contours of specific yield in this zone are shown on the map, Plate E. In the Los Angeles River area the storage capacity was computed to be 304,000 acre feet or 3040 acre feet per foot average change of water level. However, for the 50 feet below the water table of January, 1933, the average capacity per foot is only 43.5 per cent of the total, and for the 50 feet above the water table, it is 56.5 per cent. The discrepancy is so great that it should be taken into consideration in computing storage changes from the specific yield contours for the 100 foot zone shown on Plate E.

The San Gabriel River area was computed to have 304,000 acre feet capacity for the 100 foot zone or 3040 acre feet per foot; the Santa Ana area, 492,000 acre feet or 4920 acre feet per foot average change of the water table; in the Irvine area, 126,000 acre feet or 1260 acre feet per foot change of the water table.

In all areas the zone computed was uniformly 50 feet thick below the water table of January, 1933, but above the water table, although the zone averaged 50 feet, the thickness computed varied according to available storage space and probable water level fluctuations. In these areas the zone varied from 20 or 25 feet above, along the margin of the area of no storage change, to maximums of 70 or 80 feet around the hill margins. The thickness diminishes also toward the Los Angeles and Whittier Narrows, being zero in the Whittier Narrows. The lines of equal specific yield for the 100 foot zone (Plate E, in pocket) shows three prominent areas of high specific yield corresponding to the central portions of the three major river cones, with intervening areas of lower specific yields where smaller streams have deposited the sediments. The Los Angeles Cone has a maximum specific yield of about 15 per cent and the San Gabriel and Santa Ana cones about 16 per cent each. In the triangular area between the Los Angeles River Cone and the San Gabriel River Cone the specific yield drops to about four per cent; in the similar area between the San Gabriel River Cone and Santa Ana River Cone to about five per cent. From the southeast part of the Santa Ana River Cone into the Irvine area, specific yields vary between four and six per cent, being lowest around margins.

The map shows also that the specific yield decreases sharply along the margin of the area of no storage change, from the high values of the upper cones, to a yield of about eight per cent a short distance inside the pressure area. The lower yields in the area of no storage change are due primarily to the appearance of thick and extensive beds of blue and gray sedimentary clays that confine the ground water and produce artesian pressure. The low specific yields between the major river cones and near the hills are due in large part to the presence of gritty, residual, yellow and reddish-brown buried soil clays that form on the sloping alluvial surfaces during accumulation of the deposits.

The relatively high specific yields of central portions of the major river cones are due to the relative scarcity of both blue-gray sedimentary clays and yellow or reddish-brown weathered clay materials.

Ground Water in Central Basin.

Ground water of the Central Basin of the Coastal Plain is supplied in large part by the three principal rivers. This water enters the basin both as surface flow which percolates into the catchment areas, furnishing direct recharge, and by underflow through the narrows of these rivers. The San Gabriel River Narrows has the largest cross-sectional area of alluvial fill through which underflow occurs. Percolation of surface run-off from the smaller streams and percolation from rainfall and irrigation also furnish a considerable part of the ground water supply to the basin. Underflow from the smaller tributary basins within the Coastal Plain also feed the Central Basin. These are the Hollywood, La Habra and Yorba Linda basins, shown on Plate E in pocket.

Water level fluctuations in the intake areas register change of storage. These fluctuations are of less magnitude and are less sharp than those in the pressure area but the long period trends of rise and fall are parallel in both areas. The area now under pressure on the Coastal Plain corresponds roughly to the original pressure area of Mendenhall,* but the areas from which artesian flow is obtained have now shrunk to isolated spots along the coast in Orange County.

Los Angeles River Area. Ground water moves southerly and southwesterly through the Los Angeles River area from the mouth of the Los Angeles River Narrows. It escapes principally through Dominguez Gap. Small amounts escape across the uplift in places between there and the Baldwin Hills north of Inglewood, and some moves westerly through Ballona Gap at Washington Boulevard (Plate E).

Wells of the Los Angeles River area show two types of fluctuation. Those on the upper part of the cone do not recover after the pumping season until direct percolation or increased underflow raises the water table, while wells in the pressure area recover sharply at the end of the pumping season due to recovery of pressure following cessation of pumping. The record of well No. B-19b,† typical of wells in the non-pressure area, shows annual fluctuations of less than five feet per year but a net drop of about 55 feet from 1904 to January, 1933. The rise and fall of the water table as represented by this well in the storage area determines the available head for the aquifers in the pressure area and although pressure wells within the area of no storage change fluctuate 20 feet or more per year, their downward trend over the long time period parallels in a general way that of wells in the storage areas.

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* Mendenhall, W. C., U. S. Geological Survey Water-Supply Papers 137, Pls. VI and VII, 138, Pl. IV, and 139, Pl. V, 1905.

† Division of Water Resources Bulletin 39, p. 68, 1932, and Bulletin 39-A, p. 11.

Decline of the water table in the storage area and the corresponding decline of pressure levels has resulted in a gradual decrease of underflow across the Beverly-Newport uplift into the West Basin. However, a similar decline of water levels in West Basin has tended to maintain a difference in pressure levels on the two sides.

San Gabriel River Area. Ground water moves southwesterly and southerly from Whittier Narrows to mingle with the waters from the Los Angeles and Santa Ana river cones on either side. The area of free water table fluctuation lies on the upper part of the San Gabriel Cone between Atlantic Avenue and La Habra Basin (Plate E). The records of well No. C-825g* and nearby wells near the San Gabriel River and Telegraph Road give the longest records available (1904 to 1933) and are probably typical of the fluctuations of the water table in the non-pressure area. That of well No. C-825g shows from 1904 to 1925, seasonal fluctuations of less than five feet, generally with rise in the spring and decline throughout the summer. In dry years there was no rise. Since 1925 fluctuations have increased and have been from five to ten feet annually. The water table has declined sharply during this period. From this record there appears to be a direct recharge due to percolation following winter run-off, but there is a secondary rise and fall which produces a gradual cumulative rise during a period of wet years and a corresponding cumulative decline during a series of dry years. There is a lag of from one to three years in this rise and fall.

From 1904 to 1927 the water table fluctuated between five feet above and ten feet below the 120 foot elevation. Since the spring rise in 1927, before which the level had reached the low of 1904, the decline has been steady, averaging more than five feet per year and reaching a low in January, 1933, when the elevation was 85 feet. The sharp break in the trend of the record in 1927 and the following rapid depletion of storage is probably due to a variety of causes, among which are increased pumping in this basin and the San Gabriel Basin above. However, deficient rainfall and run-off since 1927 with the additional effect of a diminishing flow of rising water from San Gabriel Basin, and a decrease of underflow from the east due to decline of the water table there (La Habra Basin), are probably the principal causes.

Santa Ana River Area. The normal direction of ground water movement in the Santa Ana River area is southwesterly from the mouths of Santa Ana and Santiago canyons toward the coast, but due to heavy pumping in local areas the direction of movement is somewhat disarranged and several depression cones exist toward which the ground water moves (Plate E).

Composite records of well No. C-1129j and nearby wells,† for the period 1900 to date, show three periods of water level recovery since 1904. The first culminated in 1910 when the water level reached 98 feet elevation, the second peak was reached in 1917 at about the same level, and the third probably in 1923, although the record for that year is missing. Since 1924, however, the trend has turned more sharply

* *Op. cit.*, p. 237, and Bulletin 39-A, p. 38.
† *Op. cit.*, Bulletin 39, p. 320, and Bulletin 39-A, p. 50.

downward and by January, 1933, the water level stood only 23 feet above sea level.

Seasonal fluctuations were between five and ten feet up to 1924, with the principal rise occurring in the spring. After 1924 the sharp down trend has been accompanied by larger annual fluctuations. Direct recharge occurs in the spring following a winter of heavy rainfall, but there is also a delayed recharge which generally produces a higher water level the second spring following the wet winter. Thus the water table recoveries reached peaks in 1910, 1917 and probably 1923, following the wet winters of 1908–09, 1915–16 and 1921–22. The source of this secondary recharge is not very evident but may be due to increased flow from upper Santa Ana Basin following a wet winter.

Irvine Area. Ground water in the southeastern part of the Irvine area is derived principally from local run-off and rainfall percolation. Toward Santa Ana, underflow from Santiago Creek, and south of Santa Ana, underflow from Santa Ana River form part of the supply.

The normal direction of movement as indicated by the water level contours on Plate VII, U. S. G. S. Water-Supply Paper 137, was northwesterly toward the artesian area from the southeast arm, and southerly toward the artesian area from the vicinity of Santa Ana. At this time the artesian area practically severed the areas of storage change and the Irvine area might well have been confined to that portion southeast of the artesian area. However, from Plate E it can be seen that the influence of ground water derived from the hills around the Irvine area now has been extended northwesterly across the region of no storage change near Tustin, to the vicinity of a line running northeasterly from Santa Ana to Orange. This extension of the Irvine area northwesterly is due no doubt to the acute decline of storage in the Santa Ana River area.

Water level records are too incomplete to give a good idea of the nature of recharge or other fluctuations. However, since no barrier exists between the Irvine area and Santa Ana area and since there is no important source of ground water available directly to the area, conditions are dependent to a considerable extent upon rise and fall of water levels in the adjoining area. In 1904–05 artesian water occurred in the low area south and southwest of Tustin, maintaining a relatively constant water level in that region. However, water levels have receded to depths of 20 to 50 feet below the surface in this former artesian area. At the same time heavy pumping in the Santa Ana River area has caused this low, which formerly coincided with the surface swale, to migrate northward. Its axis now runs northeasterly from Santa Ana to Orange and the area southeast of this is supplied by local rainfall and run-off. Perched water appears in the swale where formerly artesian conditions existed, and therefore, even though water levels are lower to the north there is probably no storage change within the salient indicated on Plate E.

At Irvine the water table has dropped about 80 feet since 1904, indicating that not only has the Irvine area been affected by lowering water levels in the adjacent Santa Ana area, but the water table in the southeast part of the area, which has been supplied from local sources, has declined through the average 28 year run-off period from 1905 to

1933 also. Southeast of Tustin, there is such a high percentage of clayey material that the ground water movement is greatly impeded by it and the decline is therefore irregular, with spotted areas of perched water outside that included within the area of no storage change.

Movement of Ground Water Across the Beverly-Newport Uplift.

The Beverly-Newport structure acts in two ways to reduce the amount of underflow crossing it. First, the upfolded nonwater-bearing silts and shales rise from depths of 1500 feet or more below sea level in Central Basin to within a few hundred feet of sea level at most places along the uplift, and thus greatly reduce the cross-sectional area of the overlying water-bearing series available for underflow. However, except at the Baldwin Hills near Culver City, and in the sea cliff at Newport Beach, the nonwater-bearing materials do not reach the surface. Elsewhere the low hills along the uplift are the modified surface expression of deformation in the water-bearing series itself where it crosses the uplift.

Second, and more important, the faults which coincide with the uplift act as effective barriers to the movement of ground water. Outside the Recent fill of the surface gaps the principal underflow across the uplift appears to take place between Baldwin Hills near Inglewood and Dominguez Gap through which the Los Angeles River flows. The 1904 water level contours of Mendenhall * show a gradient away from this part of the uplift across West Basin. However, the low permeability of the uplift here is indicated by the fact that water levels were at that time about 100 feet lower southwest of the uplift than northeast of it in this area. The more continuous nature of the faulting from Signal Hill southeast probably prevents any appreciable underflow through the water-bearing series outside the Recent fill of the surface gaps.

The most important underflow across the uplift takes place through the 100 to 200 feet of Recent fill beneath the surface gaps. These gaps cut to depths of 100 feet or more below the present surfaces at a time when the land stood higher with respect to sea level, have since been filled with alluvial and marine water-bearing deposits as sea level has risen with respect to the land. Thus pervious gravel channels, deposited later than the faulted main body of the Water-bearing series, cross the uplift. Recent movement on faults has probably begun the process of forming barriers through these latest deposits.

The contours of Mendenhall † indicate underflow through the north side of Ballona Gap and through Dominguez Gap. In both cases there was a gradient in the shallow well levels through the gaps and a ground water cone spreading into West Basin.

Water levels were not available west of the uplift in the gaps southeast of Signal Hill, but the high original artesian pressure in that area and some evidence of faulting in the Recent fill would indicate that there is relatively less underflow through the Recent fill of these gaps.

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* Mendenhall, W. C., U. S. Geological Survey Water-Supply Paper 139, Pl. V, 1905.

† *Op. cit.*, Pl. VI, and Water-Supply Paper 138, Pl. IV, 1905.

LA HABRA BASIN AREA*

Location and General Description.

The La Habra Basin area occupies in the main, the long east-west synclinal trough between the Santa Fe Springs-Coyote uplift and the Puente Hills. It runs easterly from the San Gabriel River Cone to the vicinity of the Santa Ana River. The alluvial surface slopes southerly from the Puente Hills across the syncline and rises slightly as it crosses the Santa Fe Springs-Coyote uplift. The alluvial surface is eroded from the highest portions of the uplift and is dissected along the uplift where not entirely removed, and over a large part of the basin to the north. These dissected areas are covered by a deep reddish-brown weathered soil mantle.

The La Habra Basin area is subdivided into two basins, La Habra Basin and Yorba Linda Basin, by the northeastward plunging nose of the East Coyote anticline south of Brea. La Habra Basin lies to the west, and Yorba Linda to the east.

In this area there are two zones of water-bearing material (Plate III, Fig. B), the average permeabilities of which are so different that the water levels in the two are entirely distinct and their fluctuations and gradients are more or less independent of each other. The upper zone is composed principally of the older alluvium (San Dimas formation) which fills the synclinal trough from the surface to a maximum depth along the axis west of Brea of about 1350 feet. The thickness of this zone therefore varies from zero around the margins to 1000 to 1350 feet along the synclinal axis. It has a surface area of 21,100 acres in La Habra Basin, and 11,100 acres in Yorba Linda Basin. The syncline is asymmetric with its axis roughly parallel to the Whittier fault and one and one-half to two miles south of it. The contact between the two zones on the south limb slopes north at the rate of 400 to 600 feet per mile, but on the north limb it slopes south at the rate of 1200 to 2400 feet per mile. The syncline narrows and the axis rises a short distance east of Brea, where East Coyote anticline plunges northeasterly. Little is known of the structure of the synclinal Yorba Linda Basin to the east.

The lower zone is essentially a folded conglomerate (La Habra conglomerate), principally marine, but continental in the northeast part near Whittier fault. It crops out along the southern edge of the Puente Hills south of the Whittier fault and again in the Coyote Hills to the south. This zone is conformable with the underlying silt and sandy shale of the Pico formation, but a thick body of silt beneath at least a large part of the zone makes the base readily distinguishable. The lower zone is not limited to the synclinal area, but extends south across the Santa Fe Springs-Coyote uplift to the edge of Central Basin where its beds dip down beneath the alluvial fill. In part the zone may be cut off to the south by faulting (Plate B), but it seems probable, since the conglomerates become finer toward the southwest, that the gravels lense out into finer nonwater-bearing beds south of Santa Fe Springs-Coyote uplift.

* The geology and ground water conditions of this area were worked out by J. C. Kimble, Geologist of the Division staff.

The Yorba Linda Basin at the eastern end of the synclinal area lies between Richfield anticlines near Placentia (Plate B), and the Puente Hills. The northeast plunging nose of East Coyote Hills anticline, which separates this basin from La Habra Basin, tends to divert ground water to the west on one side into La Habra Basin, and to the east on the other side into Yorba Linda Basin.

The upper and lower zones both extend into this basin and are productive in at least part of the basin. The absence of deep wells in the central part of the basin between two lines of uplift makes the structural details obscure. Along the southern margin the two en echelon anticlines, the Richfield oil field near Placentia, strike a little north of east. Well logs in the oil field show the upper zone to be shallow above these anticlines. It varies there from about 350 to 500 feet in thickness. The lower zone appears from similar evidence to be between 300 and 400 feet thick. It is folded over the East Coyote Hills anticline and is exposed at the surface there in the southwest corner of the basin. A well in this area penetrates about 500 feet of La Habra conglomerate (lower zone) before reaching shale. The northeast plunge of the East Coyote anticline carries the top of the lower zone down several hundred feet below the surface along its axis, allowing a connection between Yorba Linda and La Habra basins in both the upper and lower zones. In the central part of the basin the upper zone probably exceeds 500 feet in thickness but this is not certain. The thickness of the water-bearing zone is thought to vary between 400 and 700 feet in La Habra Basin.

Character of the Water-bearing Series in the Upper Zone.

The upper zone deposits are entirely continental. In the main they are alluvial material derived locally from the Puente Hills, but in the south and southeast part of the area, deposits from the Santa Ana River are found also. The deposits from the Puente Hills are composed of reworked Puente and Pico formation shale, sandstone, and conglomerate. The coarsest debris from Puente Hills occurs along the north margin of the basin where gravels contain cobbles up to four or five inches in diameter near the mouths of canyons. The coarseness of the deposits decreases rapidly toward the south. Along the south margin of the basin, a distance of only three or four miles from the north margin, material from the Puente Hills coarser than an inch or two in diameter is rare. Where Santa Ana River deposits occur along the south margin, especially in the eastern part of the basin, cobbles from three to six inches are found.

The alluvium in this area has been more completely altered by surface weathering during its accumulation than in any other area of like size in the South Coastal Basin. Alteration has been so complete that it is difficult to get an accurate idea of the original character and distribution of the materials.

Well logs in La Habra Basin totaling 13,400 feet give an average of 90 per cent clayey material, 4.3 per cent sand, and 5.7 per cent gravelly deposits. The clays are in large part red, yellow and brown weathered soil clays, clayey aggregates of decomposed gravel, and sandy weathered clay. There is probably some depositional clay near the southern margin of the area, but from well logs and observations of the materials encountered during drilling, it appears that the greater part of the clayey material present has been formed by decomposition from gravels and sands after their deposition. The clay content is higher near the southern margin of La Habra Basin. This is probably due to the finer character of the initial deposits and to the fact that it has been an area of alternate uplift and depression, lying as it does between the La Habra synclinal axis and the Santa Fe-Coyote uplift axis.

No reliable well log data are available in Yorba Linda Basin, and therefore conditions were assumed to be similar to those of La Habra Basin, as deposition has been similar in the two basins. There is undoubtedly a high percentage of clayey material present with only occasional water-bearing gravel or sand streaks.

Character of the Water-bearing Series in the Lower Zone.

The lower zone of the Water-bearing series in the La Habra Basin area is principally of marine origin except in the northern and northeastern part where coarse continental beds occur. It is known locally as the La Habra conglomerate (page 49) and is composed of a series of poorly consolidated gravels, gray sands, soft gray micaceous sandy shales and silts, and blue and gray fossiliferous clays. The La Habra conglomerate is much more permeable and a better producer of water than the overlying clayey alluvium of the upper zone.

The gravels are coarsest along the north side of the area and there increase in coarseness toward the east. Boulders more than two feet in diameter are found in the gravels exposed northeast of Brea. Along the south margin the largest cobbles vary from two to three inches in diameter at Santa Fe Springs and in the synclinal area west of La Habra, up to five and six inches in diameter around East Coyote Hills. The direction of decrease in coarseness of the deposits is similar to that of the overlying alluvium.

The La Habra conglomerate contains granitic, metamorphic, volcanic and siliceous shale pebbles and cobbles, with some degree of concentration of the resistant light-colored pegmatite and aplite types. The sands are arkosic and the silts are characterized by an abundance of biotite. It seems probable that the source of the two series is similar, namely, the Puente and Fernando beds northeast of the Whittier fault.

The well logs show the lower zone to contain a much higher percentage of gravel than does the upper zone. In the western part, well log averages show 33 per cent of the material to be gravel, 25 per cent to be sand, and 42 per cent clay. In the eastern part of La Habra Basin the averages give 39 per cent gravel, 26 per cent sand, and 35 per cent clay. Logs of a group of wells scattered along the margin of the basin north of La Habra, excluded from the averages given above, showed an average of 52 per cent gravel, 18 per cent sand, and 30 per cent clay. This group indicates the coarser character of the materials along the north side of the area.

In Yorba Linda Basin to the east no reliable well log data are available, but conditions there are thought to be similar to those in the eastern part of La Habra Basin.

Nature of the Boundary Between the Zones.

The upper and lower zones are not separated by a continuous impervious stratum, but clay beds at the top of the lower zone do seal off a large part of the base of the upper zone. In places, however, the upper zone probably drains directly into lower zone gravels. The ground water level is maintained 100 feet or more higher over the greater part of the area in the upper zone than it is in the lower zone, because the permeability of the upper zone is so low that drainage downward into the lower zone is very slow. Ground water in the lower zone, on the other hand, moves freely out of the basin to the west and in places probably to the south. It therefore has a lower static level and a much lower gradient toward its outlet.

Specific Yield and Storage Capacity in the Upper Zone.

The storage capacity for the zone 100 feet thick, 50 feet above and 50 feet below the water table of January, 1933, was computed for La Habra Basin from well log data. The storage capacity for the 100 foot zone is 80,000 acre feet or 800 acre feet per foot average change of water level. Contours of average specific yield for this zone (shown on Plate E) give the distribution of yields within the zone. It can be seen from these contours that the highest yield is in the extreme southwest corner of the basin where a maximum is about 10 per cent. This higher yield is due to the influence of San Gabriel River and decreases rapidly toward the northeast. Over the greater part of the basin the specific yield varies between a little less than four per cent and six per cent.

Storage capacity in the upper zone of Yorba Linda Basin was computed for a 100 foot zone below the surface. The figure is 57,000 acre feet, or 570 acre feet per foot average change of the water table. This estimate of five per cent average yield is based upon findings as to La Habra Basin where conditions are thought to be similar, making allowance for higher yields along the southern margin where Santa Ana River deposits occur.

Specific Yield and Storage Change in the Lower Zone.

The area of storage change lies along the northeastern margin of the area and in the Coyote Hills (Plate B) beneath the outcrops of the zone. From well log averages and gravel coarseness the specific yield for the zone was estimated to be 12 per cent.

The zone of storage change in La Habra Basin for which storage capacity was computed, had a uniform thickness of 100 feet. The estimated storage capacity for the upper 50 feet is 33,000 acre feet and for the lower 50 feet, 40,000 acre feet. The larger figure for the lower zone is due to broadening of the horizontal extent of the zone with depth below the surface (Plate III, Fig. B). No storage capacity was computed for the lower zone in Yorba Linda Basin.

Ground Water in the Upper Zone of La Habra Basin.

Percolation of run-off from the Puente Hills, rainfall and percolation of irrigation water imported from San Gabriel River and produced from the lower zone, supply the ground water to the upper zone.

This ground water moves southwesterly and westerly from the highest portion of the basin in the vicinity of Brea Canyon, a part passing through the gap between east and west Coyote Hills (Plate E). Ground water escapes south across the uplift west of Coyote Hills and there, although it steepens along the south side of the uplift there is not a sharp break in the water table. The ground water of the upper zone merges with that of the San Gabriel River cone along the westerly margin of the basin, showing free movement of water in that direction. However, from West Coyote Hills east, there is a sharp break between water levels of the upper zone of La Habra Basin and those of the Coastal Plain to the south. In January, 1933, water levels on the north side of the Coyote Hills stood about 150 to 175 feet higher than those on the south, and in the gap between East and West Coyote Hills the upper zone levels extended into the gap, the lowest water level there being 225 feet. Water levels along the south edge of the gap stood at 50 feet elevation. This sharp break is due to the fact that the upper zone of the La Habra Basin is practically disconnected from Central Basin. The upper zone thins out to nothing along the north margin of the Coyote Hills, and in the gap between East and West Coyote Hills the thickness of alluvium is probably comparatively slight. If so, it does not permit a gradual adjustment between the two basins. It is possible also that there is a fault along the south margin of the hills which holds up levels in the gap (Plate B).

In January, 1933, the ground water elevation near the mouth of Brea Canyon was a little above 300 feet and sloped toward the west rather uniformly, its elevation being about 100 feet near the west margin of the basin, making a drop of 200 feet in the water table from the east margin to the west.

Seasonal fluctuation of water levels in the upper zone is comparatively small. Static levels in most wells vary less than five feet throughout the year. Recharge occurs directly from surface percolation and affects water levels within a month or two.

The change in water levels since 1904 has been small and somewhat erratic. In the northeast part of the basin there appears to have been practically no change. In the last few years water levels in the north central part of the basin have risen a few feet. In other parts, however, levels of January, 1933, were 10 to 25 feet below corresponding levels in 1904. Along the western margin, levels have declined 30 to 40 feet. The records are not sufficiently complete for the 29 year period to indicate whether or not there have been periods when considerable quantities of excess ground water have wasted.

In 1904 there was rising water in the low area northeast of Santa Fe Springs, in Coyote Creek where it cut through Coyote Hills, and in the gap between East and West Coyote Hills. This has ceased in the western part of the basin but in Coyote Creek and in the gap to the east, ground water still rises to the surface during most or all of each year.

Ground Water in the Lower Zone of La Habra Basin.

The lower zone of La Habra Basin is supplied with ground water by percolation of rainfall and run-off in the areas of outcrop, and by both natural downward percolation of ground water from the upper zone, and by downward movement through wells perforated in both zones. Since the lower zone is more pervious than the upper zone, ground water moves more rapidly under the same head in the lower zone. Consequently, in the areas of storage change along the north margin of the basin and in the vicinity of Coyote Hills, the lower zone has drained to a lower level over most of the basin, and throughout the central part of the basin pressure levels in wells penetrating strata of the lower zone stand lower than levels of wells in the upper zone. The hydraulic gradient of the lower zone is almost flat. In January, 1933, the elevation of water was about 120 feet, a short distance southwest of Brea. This declined to about 90 feet at the west edge of the basin. Near the south margin, levels drop off to elevations of 80 to 90 feet. There is apparently a fault (Plate B) in the vicinity of Brea which cuts through the lower zone but does not affect the upper zone, and northeast of this probable fault, water in several lower zone wells stands between 200 and 400 feet elevation. Water level records are scattered and incomplete, however, in this area and therefore, lower zone conditions in the northeast part of the basin are uncertain.

The flatness of the hydraulic gradient in the lower zone is also due to the fact that the principal source is from downward percolation of upper zone water, a relatively constant or very slowly variable source. which supplies the zone from above throughout its extent. The ground water moves with relative freedom in the lower zone and since the pumping draft is distributed throughout its area also, there is little opportunity for the ground water to establish a gradient toward the south or west basin margins.

Continuous water level records of lower zone wells are not available, but a comparison of the 1933 levels with those of 1904 shows a considerable decline in pressure which no doubt has been accompanied by a corresponding depletion of storage. The 1904 levels showed a definite downward gradient toward the west. Levels stood at about 225 feet elevation in the area between Brea and La Habra and sloped down to about 130 feet along the western border southwest of Whittier where the two zones merge. Compared with 1933 water levels, there has been a drop of a little more than 100 feet in the eastern part of the basin but a drop of only 30 to 40 feet at the western edge.

It appears that through this normal rainfall cycle the input from the upper zone probably increased through connection of the two zones by many wells, and therefore the decrease in water levels and the corresponding depletion of storage have probably occurred principally through increased pumping drafts on the lower zone, producing an overdraft in this zone not felt in the upper zone.

Ground Water in Yorba Linda Basin.

The water table in Yorba Linda Basin corresponds in a general way to that in La Habra Basin and in both zones is considerably above that of the Coastal Plain to the south. Scattered water level records indicate that ground water in the upper zone moves southerly from the mouth of Carbon Canyon and southeasterly from the mouth of Brea Canyon. It is in large part diverted by the Richfield anticlines near Placentia, one portion moving southwesterly into the Central

Basin through the saddle between East Coyote and Richfield anticlines (Plate B), the other portion moving around the southeast end of the Richfield anticlines into Santa Ana Narrows Basin. There were not enough records available for January, 1933, to determine with any degree of accuracy the shape of the water table in Yorba Linda Basin, but water levels shown on Plate VI in U. S. Geological Survey Water-Supply Paper 137 give a general idea of the direction of movement. Practically all of the water levels shown are for wells in the upper zone. A few scattered water levels for January, 1933, indicate that there has been no important decline in the water table during the period from 1904 to 1933. There are very few wells, the material is tight, and most of the irrigation water is imported by the Anaheim Union Water Company's canal from Santa Ana River. Consequently, it would seem reasonable that the ground water in storage should not have been depleted.

Very few records are available for wells penetrating the lower zone but conditions there appear to be similar to those along the south side of La Habra Basin. It may be that the lower zone is cut by a fault along the south side of Coyote and Richfield anticlines, which sustains the water table. However, upper zone levels are not affected by faulting. In the saddle between Richfield and East Coyote anticlines, shallow zone water levels show an unbroken gradient from the Yorba Linda Basin to the Central Basin both in 1904 and in January, 1933. There is a sharp drop in water levels south of the Richfield anticlines. In January, 1933, from 200 feet elevation in Yorba Linda Basin, the water table dropped 40 feet to Central Basin. The upper zone has a thickness of only 200 to 300 feet below the water table on the axes of the Richfield anticlines, and it is probably because of this comparatively small cross-section that water levels do not decline gradually toward the Central Basin.

LOS ANGELES NARROWS BASIN

Los Angeles Narrows Basin is the alluvium-filled canyon of Los Angeles River that connects San Fernando Valley with the Los Angeles River area of the Coastal Plain. The northern boundary is an arbitrary line across the valley where it becomes constricted one and one-half miles south of the center of Glendale. The south boundary is a line connecting the hills on either side, at the south end of the canyon (Plate E).

The basin is about six miles long and has a width of three-fourths to one mile throughout most of its length, but widens to about a mile and a half near the southern end. Its surface area is approximately 4000 acres.

With the exception of a small area at the northeast end of the basin, where Basement Complex and Topanga sandstones crop out, the basin is flanked and underlain by Puente sandstones and shales (Plate C). The basin is relatively shallow throughout, its depth being probably about 150 feet along the buried canyon bottom in the northern part, diminishing to 100 feet at the southern end.

The canyon fill is made up principally of Los Angeles River deposits, but there have been also contributions from the hills to the northeast, and in the southern part Arroyo Seco deposits are present also.

Well logs in this basin show some reddish-brown sandy clay near the side margins of the basin, with a large percentage of sand and small gravel through the central part. The deposits become finer toward the southern end, and the sand content is higher there.

The specific yield estimated for the entire volume of fill varies from 12 per cent at the north end of the basin, to about 16 per cent in the southern part. The ground water storage capacity was not estimated.

Underflow through the basin originates principally from San Fernando Valley, but there is also some contribution from the channel of Arroyo Seco which enters the southern part of the basin from the northeast. At times when the basin is not full, rainfall and run-off percolation add to the volume of underflow.

The seasonal fluctuation of the water table is only a few feet, and since the basin is ordinarily full to the river bed level during part of the year there is no cumulative rise or fall of the water table. Rising water generally produces a surface flow through the basin during the winter months, and in the southern part there is a surface flow during most or all of the year. Consequently, changes of storage in this basin may be considered to be negligible.

SANTA ANA NARROWS BASIN

Santa Ana Narrows Basin is the alluvium-filled canyon of Santa Ana River which runs from Upper Santa Ana Valley to the Coastal Plain, separating the Puente Hills from the Santa Ana Mountains. The basin is about 12 miles long. Its west boundary is a line marking approximately the place where the water table descends sharply from its high level in Santa Ana Canyon to the general level of Central Basin. Its east boundary is the Chino fault which separates the Narrows Basin from Chino Basin. The basin has a surface area of 6000 acres.

In the canyon, the basin has a width of from one-fourth to one-half mile, but widens to a little more than one mile at its western end. The pervious fill has a maximum depth of about 80 feet throughout the canyon, deepening to about 100 feet where it widens out in the western portion. At the extreme west end the bedrock floor dips down steeply (Plate B).

The floor and sides of the basin are made up by a variety of formations, from Cretaceous to Fernando in age. Most of these are hard and well cemented but locally coarse conglomerate and sandstone beds are present which may yield some water.

The alluvial canyon-fill contains very coarse material near the bottom, and boulders one to two feet in diameter are common there.* Logs of bore holes show sand to predominate throughout the upper part of the deposits. Gravel becomes more abundant and coarser with depth. Comparatively little clay is present in the deposits.

In the western part of the basin, water-bearing Fernando beds crop out along the south flank, and dip down beneath the alluvial fill

* Post, William S., Santa Ana Investigation, Division of Engineering and Irrigation Bulletin 19, pp. 261-264, 1928.

(Plate B). These deposits contain a large per cent of silt and clay, but sand and gravel beds are also present. Ground water from Santa Ana River channel moves into the pervious beds of this series from the east. Toward the west, the clay beds prevent return of the ground water to the overlying channel fill. Consequently, a separate and higher water level is maintained in this series than that in the overlying Santa Ana River deposits which drain readily into Central Basin.

Specific yield and storage capacity values within the canyon fill were not estimated because of the negligible fluctuation of the water table throughout most of the basin.

Rising water from Upper Santa Ana Valley flows through the canyon during all seasons of the year, and is diverted at the lower end for irrigation. Below this area of surface flow, storage changes take place, but since the amount of water involved is small and the fluctuations are essentially seasonal in character rather than cumulative, they are thought to have negligible effect upon the supply to the Santa Ana River area of Central Basin.

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APPENDIX I

THEORETICAL AND EXPERIMENTAL CONSIDERATION OF THE WATER-YIELDING CAPACITY OF CERTAIN SEDIMENTS IN THE SOUTH COASTAL BASIN

INTRODUCTION

In order to determine underground storage capacities in the South Coastal Basin it was found necessary to assign values for water-yielding capacity to the various types of materials reported in well logs. A series of experiments was therefore carried out for the purpose of estimating water-yielding capacities for the sediments.

The purpose of this chapter is: (1) to discuss and present the results of the experimental methods developed and used; (2) to formulate any laws from the results of these experiments which may be applied to the determination of the water-yielding capacities of sediments in general.

It was realized from the outset that many uncertainties exist in the application of any yield values to well logs, and therefore the experimental work was directed toward obtaining results which would give reasonable average values. The laws formulated and the yield values determined from the experimental work are considered to be valid only when applied as average values for the water-bearing materials. Since the greater part of the water-bearing materials are sands and gravels, the results described herein apply principally to these types. Comparatively little work was done to determine the water-bearing properties of finer materials such as silts and sandy clays. Therefore the results are less valid for fine materials, but since these materials occupy only a small per cent of the total, and have, furthermore, relatively low yield, errors in estimation of yield values for the fine sediments were not considered significant for the problem under consideration.

It should be borne in mind, therefore, that the conclusions reached apply chiefly to sands and gravels and can not be applied with equal accuracy to finer materials.

The results presented cover a period of two and one-half years of field and laboratory investigation. During this time many methods were tried for determining porosity, water retention, and actual water yield of different sediments. The results of other experimental work dealing with these or related problems were studied and the established methods were used whenever they appeared feasible. In some cases methods were modified to fit the local conditions and in other cases new methods were developed.

The essential difference between the experimental problems of this investigation and those of most similar previous investigations is that, in the present case, a large part of the material is too coarse and too poorly sorted to lend itself to analysis by the usual methods.

SUMMARY OF CONCLUSIONS

To emphasize certain of the important conclusions and accomplishments of this part of the investigation the following summary of conclusions is presented:

(1) Following the definition of necessary technical terms, essential theoretical considerations underlying the retention of water by a sediment are discussed and differentiation is made between the various types of retention commonly determined experimentally. It is concluded that a single set of forces, the cohesion of water and the adhesion between rock material and water, act in all types of retention and that at true equilibrium the result would be independent of the method of determination. Equilibrium is reached very slowly but practical results may be obtained in periods ranging from one season to several seasons in length.

(2) In order to make possible the transfer of results obtained for porosity, water retention and yield, to other similar samples, a method of comparison of samples by mechanical composition is presented. Detailed methods of mechanical analysis for determination of the mechanical composition of coarse sediments are given. Essential statistical constants are defined and used as a basis for the comparison of samples.

(3) In all, about 350 samples of sands and gravels were taken for the determination of porosity of typical sediments in the South Coastal Basin. Although the sources of these samples were widely distributed geographically, variations due to this distribution are not considered in this appendix, but are discussed in Chapter III. An attempt has been made to group these samples according to mechanical composition and it is shown that the average porosity can be estimated from the physical characteristics of the sediments.

In addition, the porosities of several hundred samples of consolidated materials collected from wells were determined. Discussion of these results also appears in Chapter III.

(4) During the course of this investigation, the moisture retention of about 150 samples was determined, four methods of study being used. In general the retention increases with the degree of fineness of the sediment. From an analysis of the results, it is concluded that the approximate moisture retention of **coarse sediments** can be estimated from an index of fineness, called the surface factor, which is determined from the mechanical composition of the sample.

(5) The moisture retention of sands and gravels, taken for the determination of porosity, was estimated and the specific yield of each was computed. These results are given in tables in the appendix. Direct application of these results is made in Chapter III.

DEFINITIONS

For convenience, many of the terms used in this paper are here defined. In most cases the definitions follow Meinzer.[1]

The **specific yield** of a material is the percentage of its total volume occupied by water which will be yielded under the force of gravity when the water table is lowered.

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[1] Meinzer, O. E., Occurrence of Ground Water in the United States, U. S. Geological Survey, Water Supply Paper 489 (1923).

The **specific retention** of a material is the percentage of its total volume occupied by water which will not be yielded under the force of gravity.

Thus, the **porosity,** or percentage of voids in the dry material, is the sum of the specific yield and the specific retention. The term **voids** refers to the interstices or that part of the material not occupied by solid rock material, but occupied instead by water or air. Chemically combined water is a part of the rock material and makes up no part of the porosity, retention, or yield. In certain types of sedimentary deposits (notably those containing sandstone or shale) the individual pebbles are porous. This may be considered to be a secondary porosity and in practice it is convenient to subtract it from the total porosity, considering only the remainder. If this is done the specific retention in these secondary pores is also considered secondary and is not included in the retention. This practice is justified when such pores are so small that there is no yield from them, and their porosity equals their retention.

Field capacity and **water-retaining capacity,** synonymous terms, are defined as the percentage of water by weight in a soil at equilibrium after an irrigation. For details of the methods of measuring this quantity and for the problems encountered, the original papers of other investigators should be consulted.[1]

Moisture-holding capacity is defined as the specific retention of a column of material one centimeter high. Because of the low column of material and the resultant complications caused by the capillary fringe, this property is not of interest to this investigation.

Moisture equivalent, a term introduced by Briggs and McLane,[2] is the weight per cent of water retained by a material when it is saturated and then subjected to a constant centrifugal force. In this way experimenters have reduced the capillary fringe in small samples. The centrifugal force has been standardized at 1000 times gravity and the quantity of material used is now commonly 30 grams. For details of this standardization reference should be made to the papers of Veihmeyer[3] and his collaborators.

The moisture equivalent is materially influenced by the amount of sample used and the method has been standardized for a 30-gram sample. In this investigation, the method could not be adapted, because of the relative coarseness of the materials encountered. With most of the samples here studied, it would be impossible to secure a representative sample of this size. At the inception of this work, a detailed relationship between specific retention and moisture equivalent for samples of low retention had not yet been worked out and it was concluded that in coarse materials a centrifugal force of 1000

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[1] Israelsen, O. W., Studies in Capacities of Soils for Irrigation Water, Jour. Agr. Research, Vol. 13, pp. 1–28 (1918).

[2] Briggs, L. J., and McLane, J. W., The Moisture Equivalent of Soils, U. S. Dept. Agr., Bur. Soils Bull. 45 (1907).

[3] Veihmeyer, F. J., Israelsen, O. W., and Conrad, J. P., The Moisture Equivalent as Influenced by the Amount of Soil Used in its Determination, Calif. Univ. Agr. Exp. Station Tech. Paper 16, 65 pp. (1924).
Veihmeyer, F. J., Oserkowsky, J., and Tester, K. B., Some Factors Affecting the Moisture Equivalent of Soils, First Internat'l Cong. Soil Sci. (Washington, 1927), Proc. and Papers, Vol. 1, pp. 512–534 (1928).

times gravity might remove a part of the water held by gravity (true specific retention).[1]

But one other type of retention remains for definition. The **hygroscopic coefficient** is the "percentage of water in soil, which in a dry condition, has been brought into a saturated atmosphere and kept in that atmosphere until it has absorbed all the atmospheric water vapor that it is capable of absorbing."[2]

THEORETICAL CONSIDERATIONS CONCERNING POROSITY

Since the measurement of porosity is a simple physical operation and since the various methods all quite evidently measure the same quantity, discussion of the theory underlying variation of porosity is not necessary here. Reference is made to Meinzer[3] and Slichter[4] for discussion of variation of porosity with arrangement of grains, with size of grains, with shape of grains, and with degree of assortment.

THEORETICAL CONSIDERATIONS CONCERNING SPECIFIC RETENTION

In the case of water retention, however, various methods of study of the same sample do not give identical results. Some consideration of the theory underlying specific retention therefore is desirable. Perhaps the most characteristic property of matter is that of attracting other matter. Consequently it is necessary to take this fundamental property into account when attempting to construct a theory explaining moisture retention of any kind. The attractive forces between molecules, while similar to gravitational attraction between the earth and other particles, may be of various kinds. The greatest similarity lies in the fact that all such attractive forces decrease rapidly with increase in distance between the particles considered. Two essential dissimilarities are that the attractive forces between molecules are very much greater than the gravitational forces, and that the magnitude of the attractive force varies with the nature of the molecules, whereas gravitation is independent of the nature of matter attracted.

Although the nature of these attractive forces is not exactly known, it is possible for convenience to classify them into several broad classes: (1) attractive forces which act between like molecules or other units, resulting in the property called **cohesion**; and (2) attractive forces which act between unlike substances, resulting in

[1] Since this paper was written, a manuscript: "Notes on the relation between the moisture equivalent and the specific retention of water-bearing materials" by Arthur M. Piper, United States Geological Survey, has become available. The following paragraph from this paper verifies the conclusion just reached. "Clearly the specific retention and the moisture equivalent are not equal throughout the range of the experimental data. The ratio of specific retention to the moisture equivalent is approximately unity for moisture equivalents ranging from about 12 per cent to 34 per cent of the dry weight of the material and seems to be unity at about 17 per cent. For moisture equivalents less than 12 per cent, the ratio increases progressively and is about two when the moisture equivalent is 2 per cent."

Thus it is seen that in the range of coarse sediments here considered the moisture equivalent is appreciably less than the specific retention. However, Piper shows that a relationship exists which allows the calculation of specific retention from moisture equivalent. The method deserves further study and its range of application may be extended to include even coarser sediments than those studied by Piper.

[2] Meinzer, O. E., *op. cit.*, p. 90.

[3] Meinzer, O. E., *op. cit.*, pp. 4–6.

[4] Slichter, C. S., Theoretical Investigation of the Motion of Groundwater, U. S. Geological Survey, 19th Ann. Report, pt. 2, pp. 305–328 (1899).

the property called **adhesion**. In general this paper is concerned with interfacial regions between solid (the rock materials) and liquid (water) contacts, and between liquid and gas (water-saturated air) contacts. These are true three dimensional regions and not merely two dimensional surfaces. In the region of solid-liquid interface both cohesion and adhesion are involved. If one attempts to withdraw the liquid from the solid, the cohesion of water molecule for water molecule tends to keep the water together and thus cause all of the water to be withdrawn from the solid surface. On the other hand, the adhesion at the water-rock interface tends to hold some of the water on the solid surface. In general if a liquid "wets" a solid, adhesion is greater at the contact than cohesion, and a liquid film will be left behind on the solid surface.[1] Adhesional force, while not strictly a contact phenomenon, decreases rapidly with distance from the solid surface and a point is soon reached where adhesion is equal to cohesion; beyond this point cohesion is the greater of the two quantities. The distance to this point of equality determines the thickness of the film of liquid remaining on the solid surface, and this thickness will be essentially constant on plane surfaces, provided only that the same liquid and solid are under consideration.

It will be seen that the various retentions defined above will be identical if the conditions are the same, since the forces of cohesion and adhesion are the determining factors. Any true differences must be explained by differences in the conditions of the systems involved. An analysis of various simple cases will show, for example, that specific retention and hygroscopic moisture must be equal at equilibrium. That is to say, since the same forces are acting in the two cases, the final result will be the same, whether equilibrium is approached from the "dry" side or from the "wet" side. As a matter of fact, there are serious discrepancies between the experimentally determined values of these two properties.

The sources of the discrepancies must be sought in the experimental methods rather than in the underlying theory. The difficulty is that in neither case is true equilibrium reached in periods of time which are not prohibitive.

Several investigators have made calculations based on diffusion of saturated vapor under optimum conditions which show that many years would be required to reach true equilibrium. Some experimental work in the Division of Soil Chemistry and Physics of the United States Department of Agriculture[2] demonstrate that in "a system one centimeter thick the maximum hygroscopic values are not reached even after standing 100 weeks."

Much the same condition exists in the approach to equilibrium in the case of specific retention. Meinzer[3] expresses the belief that specific retention must be defined in terms of the period of drainage. In general the hydrologist is interested in changes which take place in times ranging in length from one season to several seasons. If it could be shown that there is not a great change in specific retention between the end of the first and fifth seasons, the results obtained in a single season's drainage would be of great practical value.

[1] Harkins, Clark and Roberts, Jour. Amer. Chem. Soc., Vol. 42, p. 700 (1920).
[2] Byers, H. G., private communication.
[3] Meinzer, O. E., private communication.

It is possible that hygroscopic moisture, determined in a definite specified time, might be shown to be proportional to the equilibrium value. Thus a relationship might be worked out which would allow the calculation of specific retention from hygroscopic coefficient. In the present investigation the experimental work was directed toward working out the relation between moisture retention and a surface factor (discussed on page 233) by approaching equilibrium in various time periods from the "wet" side, that is, by drainage experiments.

Relationship Between Specific Retention and Temperature.

At first sight, it would appear that specific retention might decrease with increase in temperature, as does surface tension of all liquids, but evidence presented on this point by investigators is contradictory.

The one conclusion which can be drawn concerning the dependence of specific retention on temperature is that an increase in temperature will speed up the process of drainage. Therefore complete drainage is more closely approached in the laboratory experiments (which are carried out at temperatures above average field temperatures) than it would be in the same period in the field.

DESCRIPTION OF SAMPLES

Mechanical analyses were made as a basis for description of samples. The sieves used were made by W. S. Tyler Company, Cleveland, Ohio, and were chosen from the Tyler Standard Screen scale to fit a geometric progression. The following series of wire sieves, which were 8 inches in diameter, was used: size of openings, 0.124, 0.246, 0.495, 0.991, 1.981, 3.962, 7.925, and 15.85 millimeters. In addition, two shallow baking tins, with a square hole in one, 32 millimeters, and in the other, 64 millimeters in diameter, were used to expedite sorting of cobbles larger than 16 millimeters in diameter. All figures used in reporting grade sizes have been rounded to the nearest small proper fraction or integral value in the tables of results appended, although it should be understood that percentages reported are actually between limits in the series above.

Laboratory Routine.

Manual separation of all samples was made into two divisions, with 8 millimeters as the point of division. The fraction larger than 8 millimeters was further subdivided into grade sizes by hand. Since volume relationships are of greatest importance in connection with the determination of porosity, the volume of each class in this division was directly determined by displacement of water. This procedure avoided the determination of the specific gravity of pebbles and cobbles, which would be necessary for the calculation of volume if the separates were weighed.

The fraction smaller than 8 millimeters was weighed, and the aliquot part obtained with a Jones sampler was weighed, oven dried, reweighed, and from these results the dry weight of the entire fraction was calculated. This weight was converted into volume, using the average specific gravity of the fines. This volume added to the directly determined volume of the coarse fractions allowed the simple calculation of the porosity of the sample.

The aliquot portion, after oven drying, was separated in an electrically driven shaker. Details of procedure necessary for the standardization of results as outlined by Wentworth [1] were followed. This procedure is based upon the experience of the laboratory of the United States Geological Survey. After a careful study made by the method suggested in his paper, the time of shaking was standardized at 80 minutes. A standard Jones sampler was used and the method of use was tested, the results confirming those of Wentworth on the accuracy of the procedure.

The sample used for this part of the mechanical analysis was usually between 400 and 500 grams in weight and the fractions were weighed on a Harvard-type trip balance to the nearest tenth gram.

It is realized that the percentages reported in the tables are a hybrid of weight and volume relationships. They will be identical on the two bases only if the average specific gravity of the larger pebbles and cobbles is equal to the average specific gravity of the finer fraction. This discrepancy is not believed serious and it is felt that the results may be considered to be straight weight percentages and thus directly comparable with the results obtained by other investigators.

Certain Statistical Considerations.

The most complete description of physical characteristics of a sample is contained in the results of mechanical analysis. But even after these results have been obtained and recorded, the difficulties in comparison of similar sediments are many. Several simple graphical methods of comparison have long been in common use. In the first, or "cumulative" method, the usual custom is to plot as abscissa the percentage of material smaller than a certain grade size. The ordinate is divided into equal divisions, each division representing one grade size. In the second graphical method, the ordinate remains the same but as abscissa, the percentage of material in each grade size is plotted. The resulting curve, or histogram, is bell-shaped and resembles many other probability curves obtained in plotting physical and biological data.

Comparison of graphs of the two types mentioned would readily reveal certain gross similarities or dissimilarities, but in most cases it has been found that the differences in composition are so numerous and so subtle, that such comparison is of little practical value and may often be wholly futile.

Wentworth [2] has published the results of his study of statistical methods which might be applicable to the problem and be superior to the graphical methods. He concludes that a minimum of three elementary measures is essential as a basis for a starting point in this study.

Two of these three measures are used and will be defined and discussed here, keeping in mind the value of each as applied to prob-

[1] Wentworth, C. K., The Accuracy of Mechanical Analysis, Amer. Jour. Sci., Vol. 13, pp. 399–408 (1927).

[2] Wentworth, C. K., Method of Computing Mechanical Composition Types of Sediments, Bull. Geol. Soc. Amer., Vol. 40, pp. 771–790 (1929).

lems of ground-water hydrology. Certain additional measures will also be suggested and discussed.

The **mean size,** chosen by Wentworth as the first essential measure, most easily computed by the method of moments about an arbitrary origin, is the simple arithmetical mean, geometrically the center of gravity of the histogram, that point about which the algebraic sum of positive and negative first moments of all particles becomes zero.

The second measure, suggested by Wentworth, is the average or normal variation of sizes from this mean or the measure of deviation from perfect sorting. The **standard deviation** or the root-mean-square deviation is based on the squares of the individual deviations and hence is based on second moments. Whereas the arithmetical mean is the point about which the sum of the second moments is a minimum, the standard deviation is the square root of all the second moments about this mean. Mechanically considered, it is the radius of gyration of the figure about its center of gravity. In actual practice it has been found convenient to record the standard size ratio deviation, called the **ratio deviation** in this paper, which is the antilogarithm (base 2) of the standard deviation.

The third measure is one which evaluates the departure from symmetry of the frequency distribution curve—the **skewness.** In practice, the writer has found that the first two constants, mean size and ratio deviation, are in most cases sufficient for the classification of sediments here encountered.

Since the relative surface of a sample is of importance in connection with specific retention, an additional measure has been calculated for all samples. This constant, called the **surface factor,** is proportional to the surface per unit volume of solid material. The method of computation and discussion of surface factor is given on pages 243–246.

In later discussion reference will be made to a simple quantitative measure of the degree of uniformity in size. This measure, simpler in concept and calculation than the ratio deviation, is the **uniformity coefficient,** introduced and defined by Hazen [1] as the ratio of the diameter of a grain that has 60 per cent by weight of the sample finer than itself to the diameter of a grain that has 10 per cent finer than itself. The latter value, the **10 per cent size,** has also been called the **effective size,** and is important in connection with the study of underground velocity of flow of water.[2]

DETERMINATION OF SPECIFIC YIELD

There have been developed only two methods for the **direct** determination of specific yield and they differ only in scale; the first is the field and the second the laboratory method. In its most simple form the **field method** consists of the determination of the volume of sediments drained by withdrawal of a known quantity of water. Although it may have been used earlier, perhaps the most readily

[1] Hazen, Allen, Experiments upon the Purification of Sewage and Water at the Lawrence Experiment Station, Mass. State Board of Health, 23d Ann. Rept., for 1891, p. 432 (1892).

[2] Slichter, C. S., The Motions of Underground Waters, U. S. Geological Survey, Water Supply and Irrigation Paper 67, p. 22 (1902).

available description of the practical method is given by Clark[1] as carried out in 1904–05. The inverse of this, the determination of the volume of material saturated by a given amount of seepage from a source of water, is considered to be this same method. In practice a combination of both phases of this method is usually encountered. Difficulty in measuring the volumes of sediments drained, which, in the case of pumping drawdowns, are thin veneers covering considerable areas, make the method difficult to apply. The combination of the two phases where an appreciable thickness of material may be either dewatered or saturated over a period of years is feasible only where total inflow, outflow, and consumptive use are known. The difficulty of determining the contributions to stored water (including rainfall penetration) and losses (including evaporation and transpiration) has given the determination of specific yield its importance as a problem.

One other drawback of the method is that there is little or no possibility of transferring the results obtained to another basin, or to other parts of the same basin, because results are not obtained for each type of material, and a similar proportion of the various types in another place is improbable.

The **laboratory method** for direct determination of specific yield is the small scale counterpart of the field method. A sample of material is removed to the laboratory, where in a suitable container it is saturated and then drained, the yielded water being measured. The inverse of this method is to add a measured quantity of water to a drained sample and to determine the volume of material so saturated. The popularity of the laboratory method is due to the fact that it closely parallels actual field conditions, and that it allows accurate control of inflow, outflow, and volume of material drained. The principal objection has been that the parallel is not always sufficiently exact, because incoherent deposits are disturbed and repacked in filling the container.

In the Mokelumne investigation, the United States Geological Survey[2] filled cylinders by driving them into the material without disturbing the sample.

Many of the objections to laboratory drainage methods are overcome, as discussed later, when one considers specific retention alone. Without this simplification, the task confronting the investigator of specific yields would be so enormous as to be a physical impossibility. This point is clarified when one considers the innumerable variations of material. If porosity is a function of one property of the material and specific retention is a function of another property, the determination of porosity and specific retention for a small series of materials, may make possible the calculation of the specific yields for a large number of materials which have the various possible combinations of the two determining properties.

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[1] Clark, W. O., Groundwater for Irrigation in the Morgan Hill Area, California, U. S. Geological Survey, Water Supply Paper 400, pp. 84–86 (1917).

[2] Stearns, H. T., Robinson, T. W., and Taylor, G. H., Geology and Water Resources of the Mokelumne Area, California; U. S. Geological Survey, Water Supply Paper 619, pp. 151–172 (1930).

DETERMINATION OF POROSITY

Porosity was found to vary more widely than specific retention in sands and gravels. Therefore many more samples for porosity than for specific retention were studied, and in no case was an individual result used as such. Average porosities for groups of like samples were determined and details of the method of use of these averages appear in Chapter III.

Five methods for the determination of porosity were tried: (1) repacking incoherent deposits in the laboratory; (2) driving cylinders to obtain a known volume of material; (3) immersing consolidated samples in mercury; (4) digging pit and measuring volume of the hole with uniform sand; and (5) estimating porosity from a description of the properties of the material, the description usually consisting of a mechanical analysis.

(1) Repacking.

The method of repacking consists essentially of taking a known quantity of material and repacking it according to an adopted procedure in a container, the volume of which can be accurately determined. In work with soils, a standard device has been designed and used successfully to give comparable results with various samples. Unfortunately application of this standardized method to coarse sediments is impossible. The results obtained must bear not only the proper relationships to each other but to the porosity of the natural sediment in place. A few examples will suffice to show that the results obtained depend on the procedure adopted.

Various modifications of the method of dry-repack were tried. If one measures the volume of water which can be added to a repacked sample as a measure of the porosity, as has been done by Lee[1] the result may approach the truth because of two errors of opposite sign: (1) inability to pack sufficiently tight for true porosity; and (2) inability to add sufficient water, due to trapped air, to measure the actual porosity of the repacked sample.

Better results might be obtained by pouring the material into water and settling it. But even this method is unsatisfactory. This is true especially when there is a wide divergence in the size range of particles or where the fines would be suspended for some time.

Table 11 gives a few results obtained in this investigation by various methods and shows the degree of concordance.

TABLE 11

RESULTS OF DETERMINATION OF POROSITY BY METHODS OF REPACK

Sample number	Porosity method 2	Porosity dry repack method 2	Porosity measured in water	Porosity settled in water
G1	39.9	44.0	36.2	40.0
G2	41.0	47.0	----	42.2
G4	37.6	43.6	36.0	38.1

[1] Lee, W. T., Underground Waters of the Salt River Valley, Arizona, U. S. Geological Survey, Water Supply Paper 136, pp. 173–175 (1905).

The results given under dry repack were obtained by tapping the container until no further diminution of volume occurred. As an example of the amount of this settling, sample G 4, on merely pouring had a porosity of 47.9 per cent. The above samples were relatively fine materials. Difficulty in repacking large samples with boulders weighing from 25 to 100 pounds is obvious.

(2) Driving Cylinders to Obtain a Known Volume of Material.

The method of driving cylinders for the determination of porosity [1] is well known. The procedure followed consisted essentially in using a steel cylinder with beveled edge to measure a given volume of material, which was then removed to the laboratory, where it was dried and weighed. From their weight and specific gravity, the volume of the mineral grains was calculated, and this volume subtracted from the total volume gave the porosity.

The most severe limitation of the method is that it is practically impossible to drive the cylinder in materials containing cobbles and boulders. In certain other types of materials and in certain locations it is difficult to establish stationary reference points for the exact determination of the depth to which the cylinder is driven. It is not sufficient to measure the length of the column within the cylinder as this length does not always correspond to the length of the column of undisturbed material.

(3) Immersing Consolidated Materials in Mercury.

The porosity of consolidated materials was determined by weighing them in air and then weighing them immersed in mercury. This is a modification of the method of Melcher [2] of coating with paraffin and weighing the sample immersed in water. An application of the mercury method has been described by Gealy.[3] Calculation of the porosity is simple, given the moisture content and the specific gravity of the mineral grains.

For immersion in mercury, a thrust on an extension beneath the pan of a sensitive torsion balance was used. A single precaution should be mentioned. Some types of samples shrank appreciably when oven dried, some showed cracks in drying, while others apparently shrank as a unit. It was therefore found desirable to make the determination on a moist sample, preferably on samples at saturation. Cases were noted where this shrinkage amounted to as much as 5 per cent of the total volume. If such a sample happened to be saturated, the water yielded on drying would be greater than the apparent porosity after drying. This explains the anomaly of negative specific yields sometimes encountered.

In certain cases samples swelled appreciably on removal from their original location, because of release of pressure or imbibition of

[1] Stearns, N. D., Laboratory Tests on Physical Properties of Water-bearing Materials, U. S. Geological Survey, Water Supply Paper 596, p. 123 (1928).

[2] Melcher, A. F., Determination of Pore Space in Oil and Gas Sands, Mining and Metallurgy, Vol. 160, Sec. 5, April (1920).

[3] Gealy, W. B., Use of Mercury for the Determination of Volume of Rock Specimens in Russell Porosity Apparatus, Bull. Amer. Assoc. Petr. Geol., Vol. 13, pt. 1, pp. 677–682 (1929).

water. When samples are retention samples and are not exposed to an excess of water in sampling, they contain less water than their apparent porosity after swelling even though they were saturated in place.

Since the results obtained by this method are intimately related to the characteristics of the sediments, their tabulation is presented in Chapter III.

(4) Digging Pit and Measuring Volume with Uniform Sand.

Because of the impossibility of driving a cylinder in very coarse materials, the method of excavation was used. Students of sedimentation have long used such a method, in which they attempted to excavate a given volume of material, such as one cubic foot. In the types of material encountered in many parts of the South Coastal Basin such a procedure is impossible. With boulders up to 18 inches in diameter to be removed from the hole, it is impossible to finish with anything but a hole of highly irregular shape.

The following procedure was finally adopted. A hole was dug with these specifications to increase the precision: size of opening as small as possible; depth as great as possible, care being taken to sample but a single stratum; size of hole varying with the maximum size of boulders encountered. From the largest hole dug, about 1400 pounds of material was removed before the sample was thought to be representative. Treatment of the material has been discussed in an earlier section (pages 231–232).

In order to measure the volume of the hole from which the sample had been removed a variant of the viscous fluid method [1] was developed. The sides of the hole were smoothed as much as possible so that there were neither large re-entrants nor caverns. A measured volume of uniform sand was poured into the hole without any tamping whatever. The sand being uniform in size, had a high and uniform porosity under uniform conditions. The measuring vessels used had capacities ranging from 10,000 to 20,000 cubic centimeters, a smaller vessel being used to complete the measurement. The sand was poured into the measuring vessel slowly and carefully until it was level full. The sand was then poured into the hole at the same rate, from approximately the same height. In fact, all conditions were duplicated as nearly as possible to make the filling of the hole exactly comparable with the filling of the measuring vessel.

The method was checked by measuring a given volume of sand repeatedly and was found to be reliable. This method was found to be the most successful for the solution of the particular problem of dealing with very coarse sediments. It is not possible to check it directly against other methods because of the impossibility of driving cylinders in coarse materials.

Check determinations have been made in materials somewhat finer and these results are presented here. The main body of results of porosity determinations are to be found in the appendix.

[1] Beckett, S. H., The Use of Highly Viscous Fluids in the Determination of Volume Weight of Soils, Soil Sci., Vol. 25, pp. 481–483 (1928).

TABLE 12

POROSITY DETERMINATIONS BY METHODS 2 AND 4

Sample number	G320	G321	G322	G323	G324	G325
Map location	J6	J6	J6	J6	J6	J6
Diameter in millimeters	Percentages					
4- 8	0.3	0.5				
2- 4	3.1	2.4				
1- 2	8.2	9.0	0.7	0.9		
½- 1	18.0	18.6	10.0	7.9		
¼-½	49.3	52.2	35.8	55.8	2.5	1.4
⅛-¼	18.9	15.4	47.3	29.8	45.5	41.4
Less than ⅛	2.2	1.9	6.2	5.6	52.0	57.2
Method number	2	4	2	4	2	4
Porosity per cent	31.2	32.0	39.0	39.5	45.8	41.9

Sample number	G316	G317	G309	G310	G318	G319	G305	G306
Map location	M 14	M 14	P 13	P 13	O 9	O 9	R 15	R 15
Diameter in millimeters	Percentages							
16-32	0.3	0.4						
8-16	0.1	0.5						
4- 8	0.4	0.5	0.1	0.3				
2- 4	1.2	1.7	1.0	1.7				
1- 2	10.4	9.2	14.9	18.2				
½- 1	33.0	33.2	13.1	16.5	8.2	6.4	0.0	0.1
¼-½	41.4	45.5	53.1	48.3	73.7	78.0	1.0	1.1
⅛-¼	11.7	7.7	11.9	8.5	16.7	14.1	20.9	27.6
Less than ⅛	1.5	1.3	5.9	6.5	1.4	1.5	78.1	71.2
Method number	2	4	2	4	2	4	2	4
Porosity per cent	42.3	40.0	34.5	34.2	38.6	37.0	40.4	40.1

TABLE 13

COMPARISON OF POROSITY OF SAMPLES OF LIKE MECHANICAL COMPOSITION

Sample number	G52	G162	G97	G115	G116	G175	G90	G109
Map location	F14	F5	G29	G13	H13	G16	G30	G14
Diameter in millimeters	Percentages							
64-128	0.0	0.0	0.0	0.0	0.0	0.0	13.4	8.8
32- 64	2.3	0.4	0.0	0.0	4.9	1.7	19.2	15.0
16- 32	4.3	3.4	1.1	1.8	9.5	9.1	8.1	12.3
8- 16	6.1	8.5	0.7	1.8	10.4	14.3	4.1	9.2
4- 8	8.0	9.3	1.0	1.9	4.8	6.8	5.8	4.8
2- 4	12.7	10.6	2.9	2.2	9.8	10.7	6.5	4.5
1- 2	21.1	13.0	11.2	6.0	13.1	14.2	14.7	8.8
½- 1	23.7	23.7	22.8	23.9	19.9	14.8	16.8	16.8
¼- ½	16.7	22.0	44.4	52.7	22.1	19.2	7.5	15.7
⅛- ¼	3.2	6.7	12.4	7.7	2.9	5.4	2.5	2.7
Less than ⅛	1.9	2.4	3.1	2.0	2.6	3.8	1.3	1.4
Mean size in mm.	1.43	1.17	0.51	0.53	1.74	1.71	5.46	4.19
Surface factor	0.84	1.04	1.60	1.48	0.91	1.01	0.53	0.65
Ratio deviation	3.83	3.94	2.56	2.60	5.19	5.07	7.72	7.78
Porosity per cent	40.4	38.2	36.8	38.6	30.5	31.1	22.5	19.7

TABLE 13—Continued

Sample number / Map location	*G133 Ventura County	*G139 Ventura County	G108 G14	G181 B6	G150 C7	G79 F26	G71 G27	G123 C6
Diameter in millimeters	Percentages							
128–256	0.0	0.0	0.0	2.2	4.6	0.0	0.0	0.0
64–128	2.4	11.8	3.5	16.4	12.6	17.5	3.6	7.0
32– 64	12.1	12.6	14.7	16.5	14.4	23.1	15.6	9.5
16– 32	14.3	16.8	10.9	12.2	14.0	14.5	16.5	11.7
8– 16	14.5	14.0	7.9	9.3	11.6	8.7	15.4	9.9
4– 8	7.9	9.2	5.8	8.2	8.2	5.2	9.8	10.1
2– 4	6.7	5.3	6.0	7.6	6.2	4.2	6.1	9.2
1– 2	8.9	7.3	11.7	9.7	7.3	6.5	7.5	12.1
½– 1	12.8	9.8	21.0	8.0	9.1	8.0	8.2	12.6
¼– ½	12.2	7.9	14.3	6.5	8.0	7.9	9.7	10.7
⅛– ¼	5.1	2.5	3.2	2.3	2.5	2.5	3.4	4.4
Less than ⅛	3.1	2.8	1.0	1.1	1.5	1.9	4.3	1.8
Mean size in mm.	3.56	6.60	3.16	8.86	8.26	9.87	3.56	3.73
Surface factor	0.79	0.58	0.66	0.41	0.47	0.48	0.67	0.60
Ratio deviation	6.70	7.03	6.72	7.12	7.50	7.55	6.58	6.62
Porosity per cent	20.7	15.6	22.1	15.8	16.3	16.1	16.3	17.7

* Sample taken for Ventura County Investigation (not in South Coastal Basin).

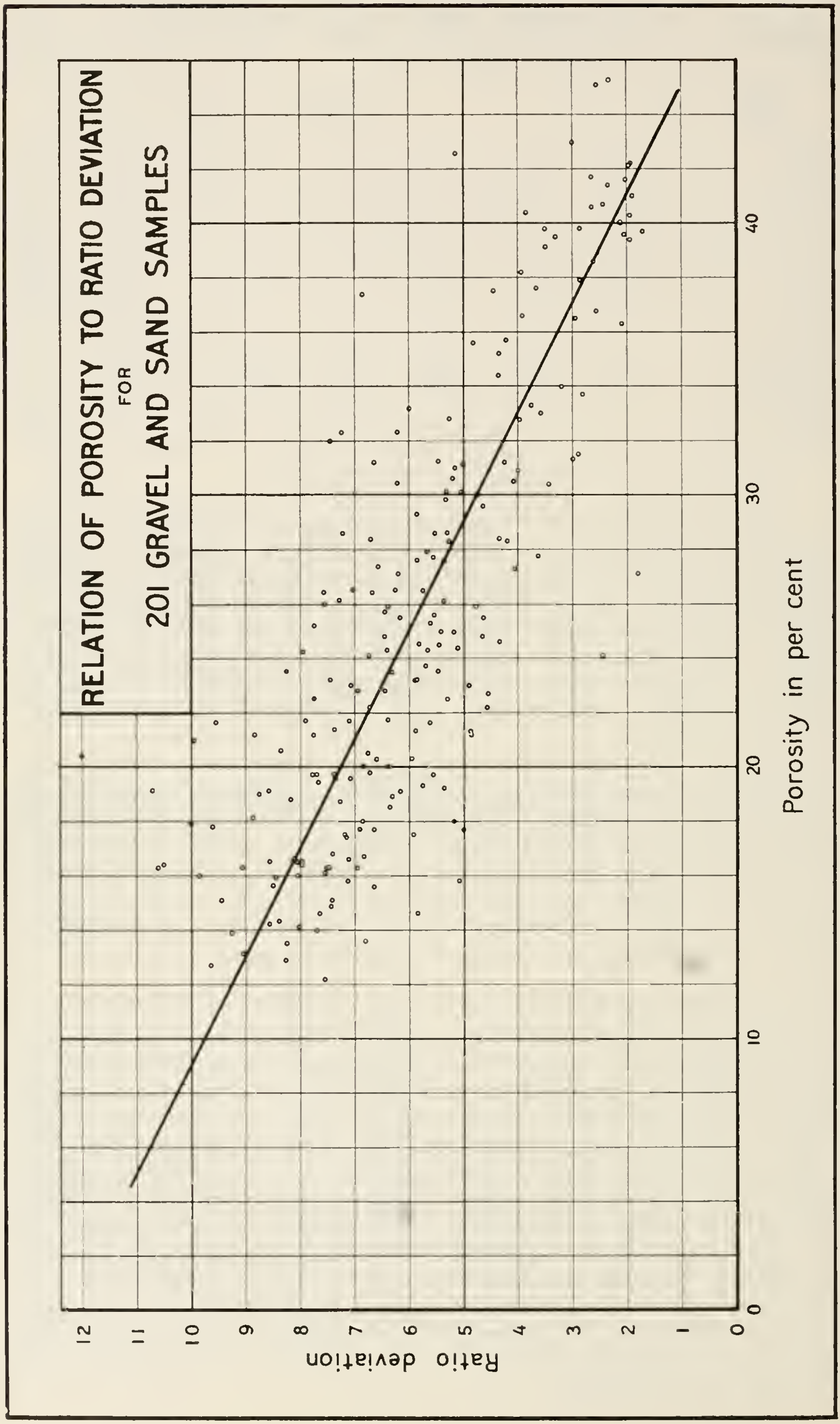
The results given in Table 12 lead to the conclusion that the method of measuring the volume of a hole with uniform sand is possibly more accurate than the method of driving a cylinder. Samples of approximately the same size were taken, and thus the samples were relatively small for application of Method 4, since the accuracy of filling the hole increases with size of hole. On the other hand, an error of one-tenth inch in the measurement of depth to which the cylinder is driven results in an error in porosity by this method of about 1 per cent.

In any case, therefore, it was found desirable to take several samples at the same location, to balance out random errors and to get a representative average. The results here cited are given to show that there are no systematic errors in Method 4. Even in these results it might be shown that part of the differences by the two methods are due to real differences in the two check samples. Since the agreement is thought to be within the limits of accuracy of the methods under consideration, no attempt to do this is made.

(5) Estimating Porosity from a Description of the Properties of the Material.

As previously discussed, it is one of the purposes of this part of the investigation to study the possibilities of estimation of porosity from mechanical composition of a sediment. Before the attempt to do this is made it must be shown that two samples similar in mechanical composition (and preferably from separate geographical locations) have approximately equal porosities. About 350 samples of sands and gravels, the porosities of which were determined, have been subjected to mechanical analysis. With from four to sixteen variables to consider, it is not surprising that exactly identical samples were not discovered. Several groups of very similar samples were found and these results are presented to show what degree of concordance may be expected in the porosity of such samples. In this connection, mean size and ratio deviation have demonstrated their value in the comparison of samples.

PLATE XXII


RELATION OF POROSITY TO RATIO DEVIATION
FOR
201 GRAVEL AND SAND SAMPLES
Porosity in per cent
Ratio deviation
0
10
20
30
40
0
1
2
3
4
5
6
7
8
9
10
11
12

The results (Table 13) show that sediments of like mechanical composition from different stream systems have like porosities. There is, therefore, a direct relationship between these two properties. Several attempts have been made by previous investigators to calculate a simple constant from mechanical analysis, which would be proportional to the porosity. The most commonly used constant is the uniformity coefficient already mentioned. Experience has shown that with the complex and very poorly sorted sediments in the South Coastal Basin such relationships are not at all exact. In previous work, only sediments with uniformity coefficients less than 10 have been considered and then only a general correlation was found. Many of the samples here described have uniformity coefficients in excess of 50. Then, too, it was found that in large groups of samples the 10 per cent size may be fairly constant, thus the variation in uniformity coefficient depends on the variation in the 60 per cent size, which is not directly related to changes in porosity.

The ratio deviation as here used gives weight to all grade sizes and does not single out any two sizes for consideration. Attempts have been made to correlate this constant with porosity but have not been sufficiently successful to allow wide use of the relation for the practical estimation of porosity.

From the graphical representation, Plate XXII, where porosity is plotted against ratio deviation, it will be seen that porosity is roughly inversely proportional to ratio deviation but individual results are widely divergent from the curve. A series of about 100 laboratory experiments was made to determine, if possible, whether these wide divergencies were real or due to random variations in porosity. The results of these experiments are not given in detail because of lack of space, but the general conclusions are discussed.

Six grade sizes were used, the maximum size being 4 to 8 millimeters. The porosity of each size was determined, when repacked dry to a minimum volume. Then various definite proportions were made up and again repacked as tightly as possible. The ratio deviation of each such mixture was calculated and compared with the lowering of porosity, calculated by subtracting the determined porosity from the calculated porosity of a mixture, using the various proportions and porosity of each pure grade size, considering the porosity to be additive. It was found that the same type of "shot gun" curve was obtained as is the case in Plate XXII: That is, samples with identical ratio deviation, but with different proportions of the various grade sizes, did not have the same lowering of porosity. The reasons for these divergencies could be followed very carefully by making up mixtures in proportions desired to show some specific effect. This method of study therefore has certain definite advantages over the method of studying natural sediments since it is not possible to get in nature the simple variations possible here.

It would seem that the method, in order to be successful, must take into account the mean size of particles as well as the ratio deviation. In Table 14, the results are distributed according to ratio deviation and mean size, the percentage reported being, in each case, the average porosity of the number of samples in the group. This number is shown in parentheses immediately below the percentage. From this tabulation it is clear that the apparent relation between mean size and porosity is due to the secondary relation between mean size and ratio deviation in natural sediments.

TABLE 14

VARIATION OF POROSITY WITH MEAN SIZE AND RATIO DEVIATION

Mean size in mm.	1/8–1/4	1/4–1/2	1/2–1	1–2	2–4	4–8	8–16	16–32
Ratio deviation	Porosity and number of samples							
1.0–2.0	39.8 (7)	39.8 (17)	----------	----------	----------	----------	----------	----------
2.0–3.0	----------	37.6 (7)	36.7 (22)	28.3 (1)	27.5 (3)	----------	----------	----------
3.0–4.0	----------	----------	35.0 (13)	36.5 (5)	30.5 (2)	----------	----------	----------
4.0–5.0	----------	----------	35.2 (1)	31.2 (13)	25.1 (9)	26.1 (3)	----------	----------
5.0–6.0	----------	----------	36.9 (2)	28.2 (8)	25.2 (25)	22.4 (17)	25.8 (7)	----------
6.0–7.0	----------	----------	----------	28.7 (5)	26.1 (19)	20.7 (17)	20.4 (6)	----------
7.0–8.0	----------	----------	----------	28.0 (3)	23.3 (5)	20.6 (14)	16.2 (14)	17.9 (2)
8.0–	----------	----------	----------	23.5 (1)	21.2 (1)	20.2 (8)	16.3 (17)	16.0 (6)

In Table 15, the direct and almost linear relation between porosity and ratio deviation is emphasized. The calculated values of porosity are obtained from the equation:

$$\text{Porosity} = 45.5\% - 3.35 \times \text{Ratio Deviation}.$$

TABLE 15

VARIATION OF POROSITY WITH RATIO DEVIATION

Ratio deviation Average R. D.	1–2 1.69	2–3 2.42	3–4 3.59	4–5 4.52	5–6 5.50	6–7 6.52	7–8 7.48	8–9 8.42
Porosity:								
Group average	39.8	35.8	35.0	28.7	25.3	23.7	19.8	17.7
Calculated	39.8	37.4	33.5	30.4	27.3	23.7	20.4	17.3

Calculated values of porosity for ratio deviations in excess of 9.0 are not given. There is some evidence that porosity may approach a lower limit of about 14–16 per cent in these sediments. Linear extension of the equation therefore would be impossible.

Whereas relationships and tabulations of the types already given are valuable in the case of averages, it is increasingly obvious that with a predominance of samples with double maxima other variables must be taken into account if one is to estimate the porosity of an individual sample from its mechanical composition. Further study, possibly with the accumulation of more samples, will be necessary before the method can be carried to the point where it will give the desired accuracy.

It should be pointed out, that in this investigation no results have been obtained which depend on the calculation of porosity, so that inaccuracies of this method do not in any way vitiate results here reported. The discussion of the indirect method for the estimation of porosity has been given here because it aids in the clarification of the general problem of applying these results to the field method. Further discussion of this direct application is given in Chapter III.

DETERMINATION OF SPECIFIC RETENTION

Relative Importance of Specific Retention.

The great range of porosities found in the sands and gravels make the determination of this property far more important than the determination of specific retention. Specific retention values are relatively small and vary but a few per cent throughout the range of the coarser sands and gravels. They rise rapidly through the range of fine sand, gravelly and sandy clays, becoming equal to the porosity as clays are approached. In most cases these finer materials (excluding clays, which yield no water), form but a small fraction of the sediments of the South Coastal Basin, and since variation in retention is most prominent in these types, small differences in the determined specific retention values have little effect upon the final computed specific yield values. With this fact in mind, experimental work was directed toward establishing a relationship between mechanical composition and specific retention, from which reasonable, approximate specific retention values might be estimated. In this chapter only the results of the determination of specific retention of relatively unweathered sands and gravels are considered. These sediments have one other characteristic which greatly simplifies the problem. They are relatively free from colloidal matter and retention of water is almost entirely a physical process without the complications encountered in ordinary soils.

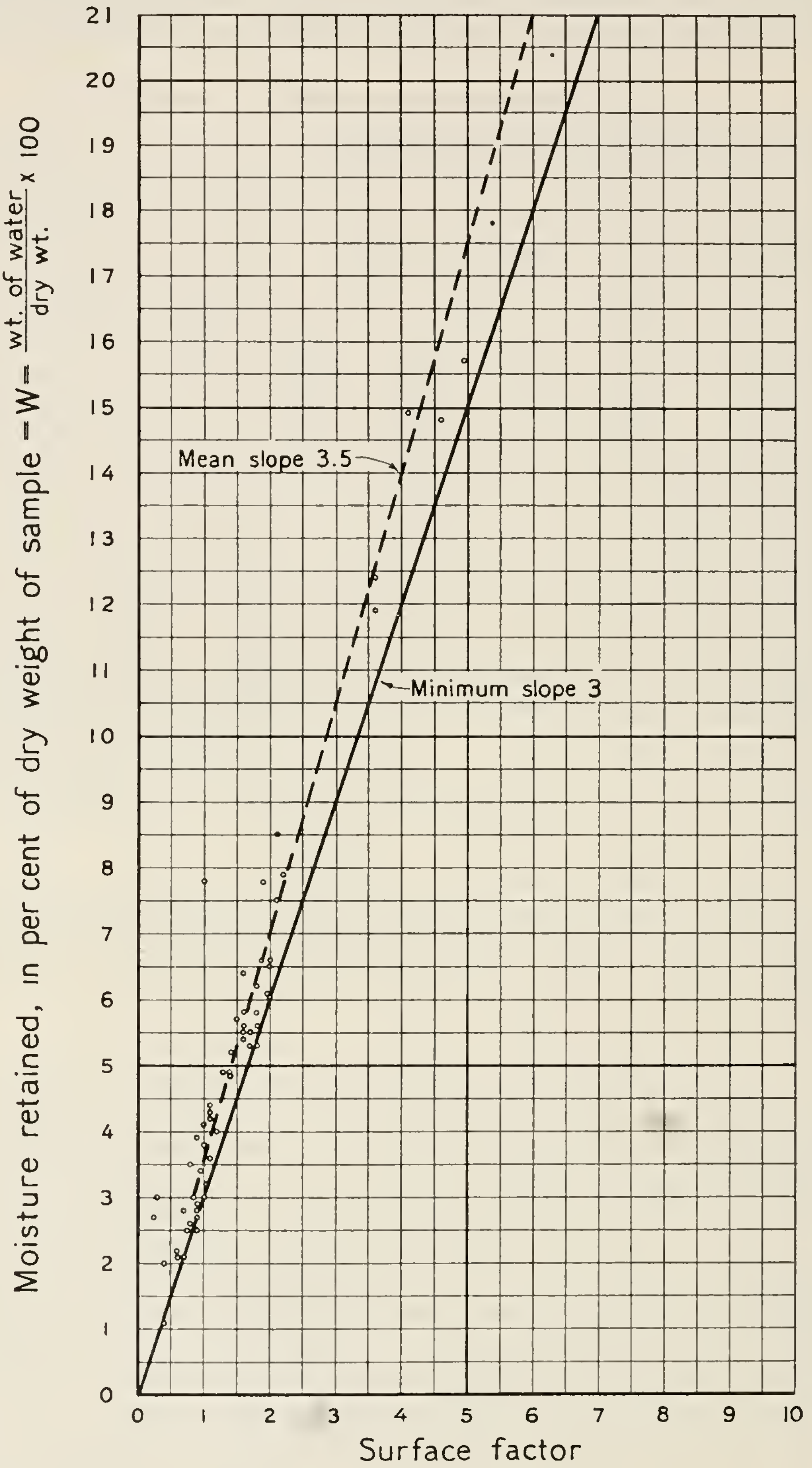
The variation in specific retention ranges from about 1 per cent to 20 per cent of the dry weight of the material but only about one sample in eight has a weight retention in excess of 5 per cent. These figures refer to the results reported in tables given in the appendix.

Relationship Between Specific Retention and Surface Factor.

It has been shown in the discussion of theory of specific retention (pages 229–230) that the physical forces controlling moisture retention are such that on a continuous surface, the thickness of the water film being essentially constant, the amount of water will be proportional to the amount of surface. Of course, in a sediment the surface is not continuous in a mathematical sense; there are cusp-like discontinuities at the points of contacts between individual particles. At these points there is a decrease in retention because of interference of films of moisture in the region of contact, but there is also an increase in retention, because at such contacts surface tension tends to round out the liquid film thus thickening it in this region.

It is impossible to estimate the relative magnitude of these two effects, but it is clear that they are of opposite sign. In general it is known that the finer a sediment the greater is the moisture retention. What is needed, therefore, is some index of fineness. The index suggested here is the **surface factor.** Experiment will be necessary to show the validity of this choice.

PLATE XXIII



RELATION OF PER CENT MOISTURE RETENTION BY WEIGHT TO SURFACE FACTOR AS DETERMINED FROM 63 SAMPLES

The surface factor is proportional to the surface per unit volume of solid material. That is:

$$s = k \frac{S}{V}$$

where s is the surface factor, k the proportionality constant, S the surface and V the volume.

Actually some simplification is necessary to allow the calculation of surface factor. With a spherical particle the formula becomes:

$$s = \frac{k\, 4\, \pi\, r^2}{4/3\, \pi\, r^3} = \frac{k\, 3}{r}$$

In applying the equation to a mechanical analysis recorded in percentages, the proportionality constant has been set at 0.1, simply to obtain results in magnitude convenient for comparison and graphical representation. In the original equation, applied to sediments, the proportionality constant includes one factor of importance. Calculation of surface is made for each grade size separately, assuming spherical particles of average radius within the grade size. The equation remains true if the average sphericity of particles is constant, the difference being accounted for in the proportionality constant. The assumption of constant average sphericity for materials ranging from sands to coarse gravels, which have been studied in this part of the investigation, is tested in the results obtained.

In reality comparisons are made between sands and sands, and between gravels and gravels. If the average sphericity of sands is different from that of gravels, this difference will show up in a change of slope in retention plotted against surface factor. From the results obtained (Plate XXIII) it would appear that this difference, probably great in fine materials, is negligible for sands and gravels in the South Coastal Basin. The above assumption can not be applied indiscriminately and would probably be invalid in the case of most soils.

The calculation of surface factor is simple. It is not computed directly from mean size of particle because in determining this quantity no consideration has been given to particles smaller than 1/16 millimeter which are included in the last grade class. Since moisture retention becomes of increasing importance with fineness of grain it is necessary to weight the material in this class higher than if there were no particles smaller than $\frac{1}{16}$ millimeter. This explains the coefficient of the first term in the series in the following equation. If the limits of this last class were $\frac{1}{8}$ and $\frac{1}{16}$ millimeter this coefficient would be 64 instead of 84.

The calculation is carried out as follows: If $p_{\overline{r_1 \text{ to } r_2}}$ is the percentage of material in the class interval between the limits r_1 and r_2 and r is the average radium in the interval the equation becomes:

$$s = 0.1 \Sigma \frac{3\,p}{r}$$

or in extended form this summation is:

$$s = 0.1 \left\{ 84\,p_{\overline{<\frac{1}{8}}} + 32\,p_{\overline{\frac{1}{8}-\frac{1}{4}}} + 16\,p_{\overline{\frac{1}{4}-\frac{1}{2}}} + 8\,p_{\overline{\frac{1}{2}-1}} + \ldots + \frac{3}{\frac{r_1+r_2}{2}}\,p_{\overline{r_1 \text{ to } r_2}} \right\}$$

Judgment is necessary in using the equation; in general it has not been used in cases where the last class interval contains more than 5 per cent of the sample. The rate of decrease of the percentage in the smaller size classes may be taken as a guide in estimating the amount of material smaller than 1/16 millimeter.

Dependence of Specific Retention on Porosity.

The possibility of an inter-relationship between specific retention and porosity is recognized. At first sight it would seem that if the porosity of a sample were decreased by compaction, since the number of contacts would be increased, the specific retention might be materially changed although the surface factor would remain constant.

Study of the results experimentally obtained, fails to show any detectable dependence of specific retention on porosity.

Experimental Methods for the Determination of Specific Retention.

Five methods for the determination of specific retention were tried during the course of this investigation. Four of these are direct: (1) laboratory drainage method; (2) collection of samples from well pits and borings; (3) cylinders driven after a rain; and (4) cylinders driven into a material, which is then saturated and drained in the field.

A fifth method, not an independent one, is the estimation of specific retention from a description of the properties of the material (surface factor). Because the method depends on the determination of specific retention of a large number of samples by other methods, details will be presented last. Wherever possible, the surface factors have been computed, and the ratio of weight of water retained, to surface factor has been given to facilitate comparison.

(1) *Laboratory Drainage Experiments.* In principle the method is identical with one commonly used for the direct determination of specific yield.[1] The experiments were essentially similar to those of King with two important modifications: (1) the cylinders (4 inches in diameter and 40 inches in length) were filled with weighed amounts

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[1] King, F. H., Principles and Conditions of the Movements of Groundwater, U. S. Geological Survey, 19th Ann. Rept., Pt. 2, pp. 86–91 (1899).
Hazen, Allen, Experiments upon the Purification of Sewage and Water at the Lawrence Experiment Station, Mass. State Board of Health, 23d Ann. Rept., for 1891, pp. 429–431 (1892).

of carefully assorted sands and a carefully measured quantity of water; (2) the withdrawal of water was through a well outside the cylinder and attached through a U-tube to the center of the bottom. Although King does not specifically mention temperature control it is assumed that some attempt was made to keep the temperature constant. In this series of experiments, the cylinders were kept in a room maintained at approximately constant temperature.

The first modification was made because it was found in this work, that even though the water was slowly added from the bottom, trapped air remained to the extent of 5 or 6 per cent. Tapping the cylinder, combined with prolonged periods of settling, removed most of the air and allowed the addition of water in quantity nearly equal to the true porosity. It is believed that nothing short of boiling would remove all of the air. Application of a partial vacuum to the top of the cylinder proved to be of little value, as the violent removal of air "boiled up" the contents, water, gravel and all, even though the greatest care was used.

The second modification, namely that dealing with the method of removal of water, is an important one in that it greatly lessens the time necessary for draining, that is it hastens equilibrium. Movement of water, when the cylinder is drained rapidly, must be largely from the bottom of the cylinder and start before the column as a whole has overcome friction and inertia. The larger capillaries drain rapidly from the top and air enters in this manner. Smaller capillaries are then broken and the entering air surrounds small regions in which capillary spaces are saturated or nearly so. Approach to equilibrium under such conditions must naturally be very slow. Rapid draining shears off the columns of water and thus nullifies in large part the forces of capillarity in pulling water down and out of small interstices. To avoid this danger and to take full advantage of surface tension the water table was lowered very slowly. It is believed that in this manner it is possible to very greatly reduce the time of drainage. Aside from the saving of time, there should be a real lessening in the amount of water lost by evaporation.

While temperature control may not be of great importance in the direct determination of specific retention, it is of greatest importance when specific yield or specific retention are to be determined from changes in water level. For a discussion of this problem, reference is made to the supplementary report of the United States Geological Survey in the Mokelumne investigation.[1] The room in which the present experiments were carried out was readily maintained at a temperature constant to within 0.1° C., for 24 hours, but fluctuations of about 5 degrees occurred over longer periods. Before any measurement of water level was made the temperature was returned to the exact initial temperature and so maintained for 24 hours. This is necessary if the same capillary fringe is to be present; if this precaution is not carried out, it is possible to obtain apparent specific yields ranging from negative values to values in excess of 100 per cent.

The samples chosen for these experiments were divided into sixteen sections with a standard Jones sampler and the sections were then put into the cylinder in turn so that the material should be very

[1] Taylor, G. H., Supplementary Report to Water Supply Paper 619, p. 160 (Manuscript, subject to revision, released Dec. 10, 1930).

uniform throughout the cylinder. The uniformity was checked by mechanical analyses of various parts of the material after completion of the experiment and found to be uniform.

Mechanical analyses of the samples in the three cylinders gave the results shown in Table 16.

TABLE 16

MECHANICAL ANALYSES OF MATERIALS USED IN LABORATORY-DRAINED CYLINDERS

Cylinder number	Size in millimeters					Surface factor s
	1–2	½–1	¼–½	⅛–¼	⅛–1/16*	
	Percentages					
1 Medium-fine sand	0.0	0.0	35.2	34.1	30.7	3.62
2 Medium sand	0.0	7.0	87.2	5.6	0.2	1.64
3 Coarse sand	1.1	91.7	6.9	0.1	0.2	0.86

* The materials were washed until they were essentially free from particles smaller than 1/16 millimeter.

Direct determinations of specific yield at 25° C., were made according to the following procedure: The water table was very slowly lowered during a period of about one month until it was thought that the capillary fringe was well below the top of the material. The water table was then allowed to approach equilibrium during a period ranging from 30 to 60 days, measurements of the water level being made almost daily. Next a measured amount of water was removed slowly, and a period of from 30 to 60 days (depending on the amount of time allowed the first time) was allowed to pass until equilibrium of water table was again approached. The difference between these two water levels was taken as a measure of the amount of material dewatered. Specific yield was then calculated directly. The difference between porosity and specific yield is the specific retention, from which the ratio of water to dry material can be calculated.

Although equilibrium may not have been achieved in the time period here used, analysis will show that the method of differences gave a result nearer to equilibrium than in a single lowering of the water table. The averages of a number of such determinations in each case is given in Table 17.

TABLE 17

MOISTURE RETENTIONS OF LABORATORY-DRAINED MATERIALS DETERMINED BY METHOD OF DIFFERENCES

Cylinder number	Porosity	Specific retention	Specific yield	$\frac{\text{Wt. of water}}{\text{Dry wt.}} \times 100$ w	Surface factor s	w/s
1	39.12	20.25	18.87	12.41	3.62	3.41
2	44.96	8.16	36.80	5.53	1.64	3.37
3	42.32	4.26	38.06	2.76	0.86	3.21

The possibility that specific retentions determined by this method were too high was recognized and consequently the cylinders were allowed to stand for an additional period of 18 months. It is not possible to say definitely just how long drainage went on in a given part of the cylinder as some parts drained continuously from the start of the experiment (a period in excess of two years) but all parts were undisturbed during the last 18 months so that this is the minimum time allowed for the approach to equilibrium.

The water remaining in the bottom of the cylinder and in the U-tube was then removed, the cylinder was slit down the side and the material removed to weighed beakers, quickly weighed, oven dried at 110° C., to constant weight. Although it was impossible to take out exactly equal amounts in each small sample and to work with the necessary speed to prevent evaporation, it was possible from the dry weights to calculate the locations of the boundaries of each sample in the cylinder. Each sample was approximately one inch in length; from 36 to 39 samples having been taken from approximately 35 inches of section.

The results are presented graphically in Plate XXIV. The curves will be seen to have three parts: (1) Starting at the water table there is a section of the curve where the moisture content decreases rather rapidly from saturation. This represents the capillary fringe. It is interesting to note that in the finer sample (Cylinder 1) there is a region of a foot or more saturated about the water table, and since the material was rather poorly sorted, capillaries were not uniform in size and the top of the fringe is not sharp as it is in the other two samples. (2) The second section of the curve is practically vertical. It is this percentage which represents the specific retention of the sample. (3) Above this second section is a section in which the moisture content again decreases. This is due to evaporation. Precautions taken in these experiments were similar to those taken by King. A check on this loss was obtained in the case of Cylinder 2, where the water accounted for was less than the water added by the calculated loss due to evaporation within the limits of error, considering the number of measurements involved. The evaporation loss was less than 200 cc.

In the case of Cylinder 3, there is a possibility that evaporation extended almost to the capillary fringe. Unfortunately in the earlier stages of this experiment there was a leak in the U-tube and it was not possible to make an accurate accounting of the water removed.

Table 18 gives the final results of drainage:

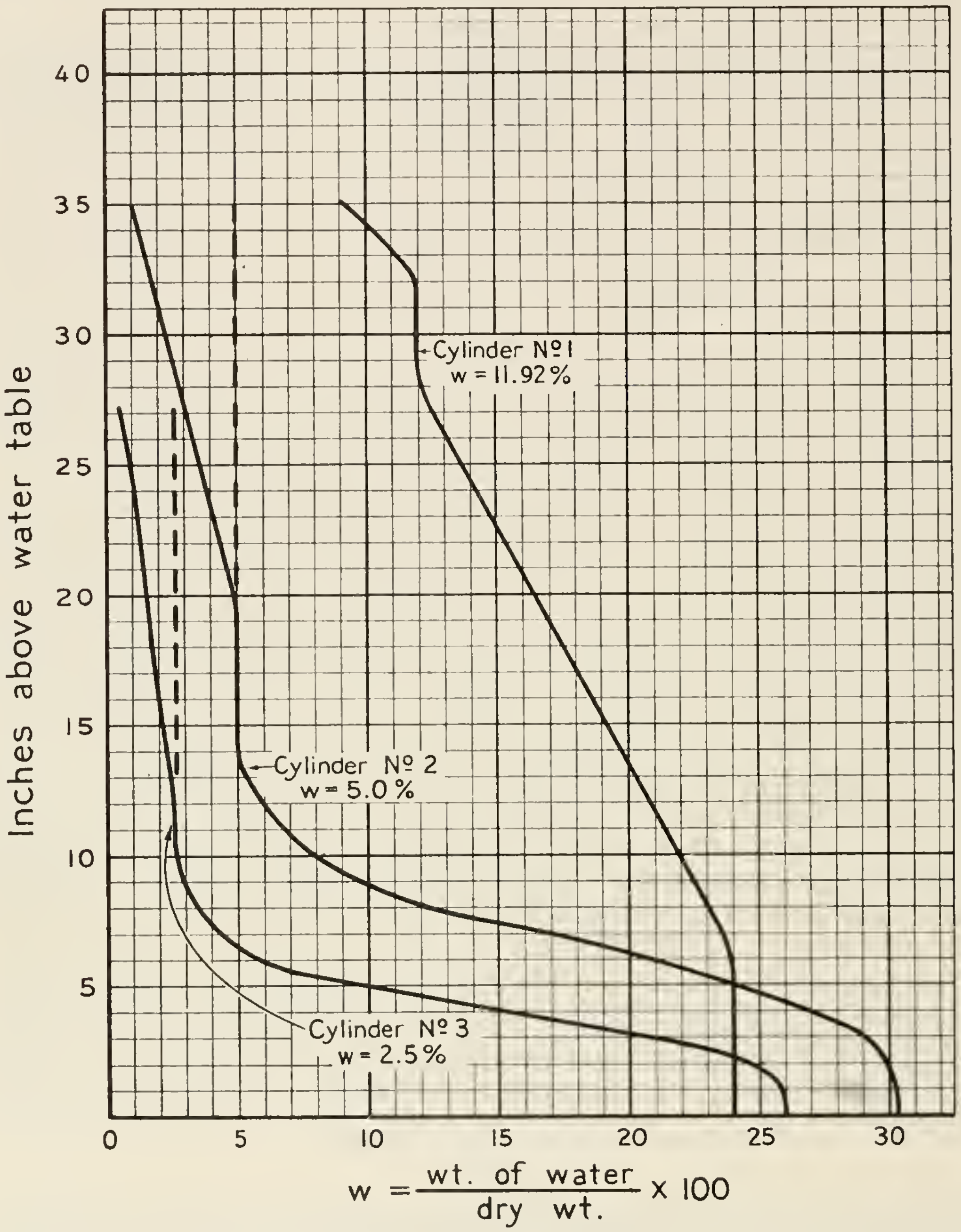
TABLE 18

FINAL MOISTURE RETENTION RESULTS FOR LABORATORY-DRAINED MATERIALS

Cylinder number	Porosity	Specific retention	Specific yield	$\frac{\text{Wt. of water}}{\text{Dry wt.}} \times 100$ w	Surface factor s	w/s
1	39.12	19.45	19.67	11.92	3.62	3.29
2	44.96	7.38	37.58	5.00	1.64	3.05
3	42.32	3.93	38.39	2.54	0.86	2.9+

The specific results for Cylinders 1 and 2 were obtained by averaging the series of six samples taken in the vertical part of the curves. The average deviation from the mean was well within the limits of

PLATE XXIV



RELATION OF MOISTURE RETAINED
TO HEIGHT ABOVE BASE
IN LABORATORY-DRAINED CYLINDERS OF SAND

error. In the case of Cylinder 3, this deviation was somewhat larger, because the zone of evaporation approached the capillary fringe more closely than it did in the first two cases.

Analysis of the results of these drainage experiments, brings out two facts of importance concerning the water-bearing properties of the materials drained. First, an inspection of the w/s ratios shows that weight per cent of retained water (w) is roughly proportional to the amount of surface (s) and that for the surface factor used, and within the limits of accuracy necessary, the ratio w/s approached 3 as an approximate lower limit constant. Second, a comparison of the weight per cents of water retained after the 30- to 60-day drainage period with the weight per cents after the additional 18-month period, shows losses of water for the second period of 0.49 per cent, 0.53 per cent, and 0.22 per cent, respectively, for Cylinders 1, 2, and 3. In all these cases, less than 10 per cent of the water retained at the end of the first periods drained out in the second, longer period. Such small differences are seen to be negligible for practical purposes, when one considers the inaccuracies of estimation involved for other factors used in computation of storage capacity. The shorter period, in this case gives results within the limits of accuracy desired, and indicates that a practical equilibrium was reached within 60 days. The more poorly sorted materials of natural deposits probably reach a practical equilibrium somewhat more slowly, but probably within periods comparable to those of the laboratory materials. Moisture retention measurements of natural sediments made by several methods and for various drainage periods are presented in the following pages. For those cases where the possibility of evaporation could be ruled out the results are thought generally to represent an approach to equilibrium and the lower values to be within the limits of a practical equilibrium for the purpose of storage capacity computation.

(2) *Collection of Samples from Well-pits and Borings for the Determination of Retention.* This method consisted essentially in the collection of samples from pits which were being dug to the water table and from auger borings. In the case of well-pits, a jar was lowered to the man on the job. He selected freshly uncovered material and filled the jar, which he then sealed and sent to the surface. Moisture content was determined in the laboratory.

Ellis and Lee[1] used a comparable method in San Diego County, where they dug pits to the water table and sampled the materials that were drained as the water levels fell in the summer. The danger of presence of the capillary fringe after lowering is to be considered in such an experiment.

In the method here used the natural lowering of the water table was utilized, but periods of drainage extending over several years could be used because of the general drop of the water table in recent years. This fact introduces an uncertainty as to the exact time of drainage, but results in what is practically a direct determination in the field of the quantity sought. The only way in which materials, once saturated, could contain less water than the true retention would

[1] Ellis, A. J., and Lee, C. H., Geology and Groundwaters of the Western Part of San Diego County, California, U. S. Geological Survey, Water Supply Paper 446, p. 121 (1919).

be by evaporation out of this zone into the air. In parts of the South Coastal Basin pits have been dug to a depth of 500 feet before capillary fringe water was encountered. Even with marked circulation of air, due to changes of temperature, changes of atmospheric pressure, and fluctuations of the water table, it is difficult to believe that there is appreciable loss at depth.

It was found to be important that a more or less continuous section of samples be taken from the pit. This was necessary in order to avoid the possibility of results which were too high because of the presence of waters en route to the water table from previous rains or returning irrigation waters.

The same considerations were applied to samples taken by auger borings, the essential difference being in the depths from which the samples were obtained. The results obtained in a study of moisture content of samples taken from well pits are presented first.

In order to determine the extension of the range of moisture retention into finer sediments, in some of these samples the material smaller than ⅛ millimeter in diameter was divided further so that the percentage smaller than 1/16 millimeter was determined. This separation was carried out by sedimentation in water; calibration of the method was carried out with a micrometer microscope. This change in method requires a corresponding modification in the equation for surface factor; the coefficient for grade size with limits ⅛ to 1/16 millimeter becomes 64, and 180 is chosen as coefficient for the material smaller than 1/16 millimeter.

Some of the results obtained from a study of the moisture content of samples collected above the water table from pits dug preparatory to the drilling of wells are given in Table 19.

TABLE 19

MECHANICAL ANALYSES AND MOISTURE RETENTIONS OF PIT SAMPLES FROM ABOVE THE WATER TABLE

Well No. C665m

Sample number	2b	4b	2	3
Depth in feet	132	145	170	180
Diameter in millimeters	Percentages			
16–32	0.0	0 0	22 1	3 0
8–16	3 5	0 0	15.7	12.0
4– 8	9.4	0.5	8.5	12.3
2– 4	11.6	0.5	9.8	11.5
1– 2	23.6	1.0	10.3	14.0
½– 1	26.0	20.1	12.9	14.1
¼–½	12.6	6.3	12.4	17.1
⅛–¼	4.0	10.9	4.3	7.8
Less than ⅛	9.3	4.1	4.0	8.2
Less than 1/16	4.3	----	----	----
$w = \frac{\text{Wt. water}}{\text{Dry wt.}} \times 100$	9.03	7.81	2.68	4.85
s= Surface factor	1.76	1.87	0.86	1.43
w/s	5.13	4.18	3.12	3.40

TABLE 19—Continued

Well No. C656m

Sample number	1a	1b	3a	4a	4b	5a	5b	7a	7b	8a	8b
Depth in feet	325	325	370	373	373	412	412	458	458	460	460
Diameter in millimeters	Percentages										
32–64	0.0	15.7	0.0	0.0	0.0	22.7	15.7	0.0	0.0	0.0	0.0
16–32	17.3	16.6	0.0	31.2	18.0	16.9	26.7	0.0	0.0	10.9	24.8
8–16	9.5	9.5	1.9	11.2	11.2	10.7	11.8	4.2	2.7	15.8	11.0
4– 8	10.4	7.2	1.1	7.3	7.4	6.2	5.8	1.6	1.2	6.1	5.2
2– 4	9.2	7.4	1.0	6.7	8.2	5.8	5.5	2.6	3.1	7.6	7.9
1– 2	14.0	11.2	2.7	10.6	12.7	8.1	7.2	6.8	6.8	13.6	11.8
½– 1	18.9	14.5	5.7	11.8	14.1	9.6	8.7	11.5	10.8	15.3	6.5
¼–½	12.9	10.9	14.4	10.6	14.6	10.8	10.4	16.7	16.7	14.4	18.9
⅛–¼	4.1	3.6	17.2	4.2	5.7	4.7	3.8	16.5	16.3	5.0	6.8
Less than ⅛	3.6	3.5	56.0	6.3	8.1	4.5	4.3	40.1	42.4	11.3	7.1
Less than 1/16	-------	-------	15.9	2.3	2.1	-------	-------	9.9	11.4	6.0	3.9
w = Wt. water / Dry wt. x 100	2.94	2.56	20.39	5.09	5.17	5.33	5.35	14.81	15.71	6.61	5.51
s = Surface factor	0.89	0.78	6.26	1.14	1.37	0.84	0.78	4.64	4.95	2.02	1.56
w/s	3.30	3.28	3.26	4.46	3.77	6.35	6.86	3.19	3.17	3.27	3.53

Well No. 656m

Sample number	11a	11b	12a	12b	13a	13b	14a	15b	16a	16b	17a
Depth in feet	490	490	500	500	505	505	510	511	516	516	521
Diameter in millimeters	Percentages										
32–64	0.0	0.0	0.0	14.0	14.8	0.0	42.1	0.0	13.3	0.0	0.0
16–32	29.6	25.5	24.7	13.4	26.6	42.5	3.9	4.6	5.9	15.5	5.5
8–16	7.2	10.1	10.8	17.7	10.4	11.2	7.3	14.8	7.7	10.9	16.0
4– 8	5.8	6.8	7.9	8.8	6.3	9.2	5.9	11.7	4.2	8.3	12.3
2– 4	6.0	6.8	10.5	8.8	7.2	5.4	7.0	6.1	6.8	5.9	10.9
1– 2	10.8	10.8	13.9	11.4	9.1	8.3	10.4	13.3	13.2	11.8	16.4
½– 1	16.0	9.2	13.0	10.3	10.2	9.1	10.9	14.5	15.8	16.3	15.8
¼–½	15.4	20.4	10.0	7.4	6.4	7.7	7.4	18.5	14.9	14.7	9.4
⅛–¼	5.2	6.3	4.0	3.9	5.2	3.6	2.1	6.4	6.4	6.3	3.9
Less than ⅛	4.0	4.1	5.2	4.3	3.8	3.0	3.0	10.1	11.8	10.3	10.0
Less than 1/16	-------	-------	-------	-------	-------	-------	-------	*4.8	*4.8	*4.1	*4.0
w = Wt. water / Dry wt. x 100	3.39	3.84	4.49	3.84	4.28	3.78	5.42	7.46	6.05	5.33	**9.63
s = Surface factor	0.95	1.02	0.92	0.77	0.74	0.63	0.60	1.91	1.96	1.78	1.61
w/s	3.57	3.76	4.88	4.99	5.78	6.00	9.03	3.90	3.09	2.99	5.98

* See discussion immediately preceding this table for special methods.
Capillary fringe evident at 520 feet; water table at 525 feet.

Well No. C528c

Sample number	1	3	4	5	6	8	9	10	11	12	13
Depth in feet	95	135	145	157	165	185	195	205	215	225	235
Diameter in millimeters	Percentages										
32–64	0.0	0.0	0.0	0.0	9.8	0.0	0.0	0.0	0.0	0.0	0.0
16–32	3.6	16.0	12.7	18.7	18.8	10.9	10.1	0.0	3.4	18.0	10.1
8–16	6.0	9.4	12.6	16.6	12.8	10.5	11.4	3.2	19.2	9.4	19.4
4– 8	11.0	10.4	14.2	10.9	7.8	9.8	11.5	3.6	13.5	8.8	16.1
2– 4	15.2	10.5	14.3	8.4	7.6	8.0	13.1	7.0	11.4	9.0	10.7
1– 2	20.0	11.1	11.4	7.3	10.9	9.4	15.8	13.2	13.5	9.2	10.2
½– 1	16.4	14.7	13.3	9.1	11.9	13.7	16.3	27.1	15.5	13.9	11.1
¼–½	17.6	14.9	11.4	15.4	11.0	17.4	12.7	29.4	13.1	17.6	11.1
⅛–¼	6.1	5.4	4.7	6.1	2.7	9.5	4.8	10.0	6.1	8.1	5.9
Less than ⅛	4.1	7.6	5.4	7.5	6.6	10.8	4.3	6.5	4.3	6.0	5.4
Less than 1/16	1.0	3.1	1.4	3.1	3.6	4.3	1.9	1.9	-------	-------	-------
w = Wt. water / Dry wt. x 100	4.17	6.76	8.38	4.90	5.21	6.46	4.32	5.47	3.93	5.61	6.43
s = Surface factor	1.11	1.46	1.05	1.42	1.28	1.95	1.09	1.72	0.99	1.23	1.00
w/s	3.76	4.63	7.98	3.45	4.07	3.31	3.96	3.18	3.97	4.56	6.43

The relative moisture retention for the 37 pit samples listed in Table 19 is considerably higher than that for the materials drained in the laboratory. The average w/s ratio for the pit samples is 4.42, as against 3.08+ for the laboratory materials. Only the lowest values for the pit samples approach the laboratory determinations. However, since there is probably an excess of water present in parts of the zone penetrated by the pits due to returned irrigation waters and rainfall penetration, it is thought that only the lowest values represent an approximate equilibrium. Since these lower values do correspond to the laboratory determinations, it seems probable that they are reliable.

In Table 20, the results of moisture determinations in samples obtained by post auger boring in relatively fine sediments are shown.

TABLE 20

MOISTURE RETENTION DETERMINATIONS OF POSTAUGER SAMPLES

Boring F 2
Location G 13 — Section in Rio Hondo wash. Drainage period about six months from date of last rain.

Sample 1
w=26.5% — Moist quicksand taken below 8″ dry sand. Depth 12″–16″.

Sample 2
w=18.8% — Quicksand with streaks of medium sand. Depth 16″–20″.

Sample 3
w=4.84%
s=2.43 — Medium well-sorted sand. Depth 26″–34″.

$\frac{w}{s}=2.0$ — Possibility of evaporation loss is recognized.

Boring F 3
Location I 12 — Rio Hondo wash. Drainage period about six months from date of last rain.

Sample number	1	2	3
Depth in inches	38	58	110
Diameter in millimeters	Percentages		
8–16	2.9	0.0	1.4
4–8	4.1	2.0	1.9
2–4	10.9	3.9	1.2
1–2	15.4	15.8	3.0
½–1	22.3	36.5	16.2
¼–½	30.1	25.9	55.7
⅛–¼	9.8	9.7	12.6
Less than ⅛	4.5	6.2	8.0
$w=\frac{\text{Wt. water}}{\text{Dry wt.}} \times 100$	3.10	3.80	4.54
s=Surface factor	1.44	1.61	2.11
w/s	2.15	2.36	2.15

Hole drilled to total depth of 150″; no evidence of capillary fringe; possibility of slight evaporation loss in upper samples is recognized.

Boring F 5
Location I 13 — San Gabriel River bed. Drainage period about six months from date of last rain.

Sample 1 — Sample of medium well-sorted sand, which continued from surface to 108″, where clay was encountered. Drilled 18″ in wet clay. Depth of sample 62″.

Diameter in millimeters	8–16	4–8	2–4	1–2	½–1	¼–½	⅛–¼	Less ⅛
Percentages	1.0	1.4	3.0	11.7	44.4	32.8	4.7	

w=3.27%, s=1.17, w/s=2.80.

TABLE 20—Continued

Boring F 6 — Rio Hondo wash. Drainage period about six months from date of last rain.
Location M 10
Discarded: 12″ fine dry sand, 18″ fine moist sand.

Sample number	1	2	3
Depth in inches	32	48	66
	Percentages		
Diameter in millimeters			
8–16	0.0	1.0	0.0
4– 8	0.0	0.8	0.1
2– 4	0.0	0.6	0.3
1– 2	0.1	2.3	0.8
½– 1	0.2	6.4	6.1
¼–½	33.6	37.4	40.3
⅛–¼	47.6	40.2	41.0
Less than ⅛	18.5	11.3	11.4
$w=\frac{\text{Wt. water}}{\text{Dry wt.}} \times 100$	4.80	5.91	6.96
s=Surface factor	3.62	2.90	2.97
w/s	1.33	2.04	2.35

Examination of fractions smaller than ⅛ mm. shows but slight amount of material smaller than 1/16 mm., so that surface factors are essentially correct despite large percentages in last class. The regular increase in the ratio w/s would seem to indicate evaporation losses.

Sample 4 w=14.0% — Yellow clay, depth 74″.

Sample 5 w=15.0% — Yellow clay, depth 82″.

Sample 6 w=18.1% — Blue clay, depth 92″.

Boring F 7 — Rio Hondo stream bed. Drainage period about six months from date of last rain.
Location J 11
Discarded: Medium to coarse sand overlying clay and silt.

Sample number	1	2	3
Depth in inches	58	86	110
Porosity (Method 3)	29.3	29.2	48.6
Retention %	29.3	29.3	49.2

Samples 1 and 2 were silts; sample 3, a fine, silty sand. Water encountered at approximately 114″; lower samples apparently in capillary fringe; upper sample also saturated.

Boring F 8 — San Gabriel River bed. Drainage period about six months from date of last rain.
Location J 12

Discarded: 80″ sand.
Sample 1 — Medium sand; sample taken in core barrel, porosity Method 2. Porosity 42.7%, retention 5.2% apparent yield 37.5%.

Sample 2 — Depth 130″. Medium sand. Porosity 40.6%, retention 7.8%, apparent yield 32.8%.

Size in mm.	4–8	2–4	1–2	½–1	¼–½	⅛–¼	Less than ⅛
Percentages	0.1	0.1	2.5	25.5	46.2	17.8	8.0

w=4.90%, s=1.93, w/s=2.54.

Sample 3 — Depth 192″. Coarse, poorly sorted sand. Porosity not determined.

Size in mm.	8–16	4–8	2–4	1–2	½–1	¼–½	⅛–¼	Less than ⅛
Percentages	3.0	3.2	5.1	11.4	23.7	31.9	11.2	10.5

w=3.89%, s=2.00, w/s=1.95.

Boring F 9 — San Gabriel River bed.
Location K 12

In this section a series of ten samples was taken; most of them were fine-grained silts or clays and many of them were saturated. These samples were not suitable for ordinary mechanical analysis and the results are presented elsewhere. One sample is of great importance in the present connection.

Sample 8 — Depth 306″. Medium fine sand.

Size in mm.	1–2	½–1	¼–½	⅛–¼	Less than ⅛
Percentages	0.4	6.5	72.3	17.8	3.0

w=6.29%, s=2.01, w/s=3.13.

In this sample there was probably no evaporation loss; the sample is from the greatest depth yet recorded, and was overlain by section of very fine material. some of which was saturated. Ratio w/s is the largest recorded in this section for similar material and closely approaches the limit for this ratio by other methods.

The relative moisture content of the post auger samples was considerably below that of the pit samples and somewhat less than that of the laboratory materials. The average w/s ratio for the eleven samples for which surface factors were computed is 2.3 and only the highest value (3.13) approximates the 3.08+ average for the laboratory results.

The post auger samples were obtained from borings in the beds of dry washes where no vegetation was present. It seems probable that air circulation occurred through the permeable beds for some distance below the surface and thus produced evaporation losses in these materials. In this connection it is interesting to contrast the results from the pit samples with those from the post auger samples. As pointed out previously, the possibility of moisture losses by evaporation from the materials sampled in pits seems remote, but additions by percolation from above seem probable. In the case of the materials sampled with the post auger, the reverse was true. The possibility of moisture additions from the surface does not appear to have been possible, but evaporation losses to the depth sampled seems probable. However, the lower limit of the w/s ratio for the pit samples, and the upper limit of the w/s ratio for the post auger samples are both about the same, and are approximately equal to the w/s ratios for the laboratory material (Method 1).

(3) *Cylinders Driven After Rain.* Essentially this method is one for the measurement of field capacity. Steel cylinders 18 inches long, 4 and 8 inches in diameter, were driven into a sand or gravel stratum, carefully removed and returned to the laboratory w[illegible]re the moisture content of the materials was determined. These samples were taken about 36 to 48 hours after a heavy rain and were followed in another like period by a similar sampling of the identical stratum. In a few cases similar tests were made in stream beds at various intervals after the streams had ceased to flow.

Standard laboratory practice was to divide the contents of the cylinder into 3 to 12 approximately equal divisions and to make a moisture determination and mechanical analysis of each division. This procedure gave a check on the uniformity of the stratum sampled and upon the amount of evaporation as well as on the completeness of drainage. Some of the results obtained by this method are reported in Table 21. Complete mechanical analyses for most of the composite samples may be found in the appendix.

TABLE 21

MOISTURE RETENTION DETERMINATIONS O[illegible]MPLES TAKEN AFTER RAINS

Sample G 1. Location J 22. Porosity 39.9%. 36 hours after [illegible]y rain.

Division	1	2	3	4	[illegible]	6	7	8	9
m=Mean size in mm.	0.38	0.34	0.34	0.38	.36	0.34	0.43	0.56	0.51
s=Surface factor	1.96	2.07	2.14	2 02	1.99	2.14	1.70	1.50	1.59
w=Moisture per cent	7.76	8.50	8.28	8.81	8.64	10.01	8.23	6.38	6.44
w/s=	3.96	4.06	3.87	4.36	4.34	4.68	4.84	4.25	4.05

Averages: w=8.11±0.83; w/s=4.27±0.25.

Sample G 2. Location J 22. Porosity 41.0%. 72 hours after heavy rain.

Division	1	2	3	4	5	6	7	8	9	10
m=Mean size in mm.	0.34	0.32	0.35	0.38	0.41	0.40	0.45	0.45	0.56	0.60
s=Surface factor	2.10	2.22	1.95	1.83	1.79	1.83	1.59	1.59	1.33	1.32
w=Moisture per cent	7.47	7.87	6.10	5.76	5.60	6.16	5.82	5.54	5.37	4.94
w/s=	3.56	3.55	3.13	3.15	3.13	3.37	3.66	3.48	4.04	3.74

Averages: w=6.06±0.68; w/s=3.48±0.23.

TABLE 21—Continued

Sample G 3. Location G 20. Man-made deposit of high porosity, used as filtering ground for rockcrusher. 36 hours after rain.

Division	1	2	3	4	5	6	7	8	9
m=Mean size in mm.	1.01	1.12	1.22	0.97	0.98	0.63	1.58	1.83	2.03
s=Surface factor	1 06	0 97	0 94	1 08	1.08	0 96	0 83	0.71	0 73
w=Moisture per cent	4.44	4.55	3.90	4.71	4.71	4.49	3.52	3.41	3.52
w/s=	4.19	4.69	4.15	4.36	4.36	4.68	4.24	4.80	4.82

Averages: w=4.14±0.49; w/s=4.48±0.24.

Sample G 4. Location F 17. Porosity 37.6%. 72 hours after rain. Wetness increased lower in section, perhaps because of perched water.

Division	1	2	3	4	5
m=Mean size in mm.	0.48	0.51	0.55	0.52	0.60
s=Surface factor	1.67	1.62	1.57	1.67	1.76
w=Moisture per cent	5.26	5.57	5.84	7.16	7.62
w/s=	3.15	3.44	3.72	4.29	4.33

Averages: w=6.29±0.88; w/s=3.79±0.41.

Sample G 6. Location G 17. Porosity 35.7%. 72 hours after rain.

Division	1	2	3	4	5	6
m=Mean size in mm.	1.31	1.45	1.80	1.09	1.12	2.33
s=Surface factor	1.07	0.99	0.97	1.29	1.08	0.80
w=Moisture per cent	3.56	3.87	4.09	5.15	4.74	3.81
w/s	3.33	3.91	4.22	3.99	4.39	4.76

Averages: w=4.20±0.49; w/s=4.10±0.35.

Sample G 7. Location G 17. Porosity 35.6%. 72 hours after rain.

Division	1	
m=Mean size in mm.	1.78	Divisions 2 and 3 of this sample were decomposed and broke down in shaker; unable to get surface factor.
s=Surface factor	0.89	
w=Moisture per cent	2.68	
w/s=	3.01	

Sample G 11. Location F 20. Porosity 27.6%. 72 hours after rain.

Division	1	2	4
m=Mean size in mm.	22.4	2.6	3.4
s=Surface factor	0.27	0.77	0.65
w=Moisture per cent	1.29	3.01	2.68
w/s	4.78	3.91	4.12

Averages: w=2.33±0.69; w/s=4.27±0.34.

Sample G 12. Location F 20. Porosity 28.6%. 72 hours after rain.

Division	1	2	3
m=Mean size in mm.	7.66	2.75	2.40
s=Surface factor	0.36	0.67	0.64
w=Moisture per cent	1.09	2.08	2.08
w/s	3.03	3.10	3.22

Averages: w=1.74±0.43; w/s=3.12±0.07.

Sample G 13. Location G 20. Porosity 23.2%. 72 hours after rain. Cylinder driven horizontally.

Division	1	2	3
m=Mean size in mm.	3.79	2.95	2.71
s=Surface factor	0.75	0.74	0.70
w=Moisture per cent	2.51	2.54	2.83
w/s=	3.35	3.43	4.04

Averages: w=2.63±0.14; w/s=3.6[illegible]9.

Sample G 22. Lo[illegible] %. Driven in stream bed and allowed to remain 13 days after stream had ceased flowing.

Division	1	2	3
m=Mean si[illegible]	0.43	0.84	0.80
s=Surface fac[illegible]	2.18	1.58	1.05
w=Moisture per [illegible]	5.24	4.67	3.17
w/s	2.4*	2.96	3.02

*Possibly some evaporation loss.
Averages 2 and 3; w=3.92±0.75; w/s=2.99±0[illegible].

None of the results for the 36- or 72-hour periods represent equilibrium, but drainage is much more rapid in such short columns than in long columns of material.

Even with periods of drainage as short as these, there appears to be a definite tendency toward a constant relationship for the w/s ratio. In Table 22, are summarized the average deviations expressed in percentages of retained water (w) and of the proportionality factor (w/s). It will be seen that the variation in w/s is only about

TABLE 22

AVERAGE DEVIATIONS IN PER CENT OF W, AND W/S RATIOS FOR SAMPLES TAKEN AFTER RAINS

	Average deviations, %	
Sample number:	w	w/s
G- 1	10.2	5.9
G- 2	11.2	6.6
G- 3	11.8	5.4
G- 4	14.0	10.8
G- 6	11.7	8.5
G-11	29.6	8.0
G-12	24.7	2.2
G-13	5.3	8.0
G-22	19.1	1.0
Averages	15.3	6.3

one-third the average variation in w, even before equilibrium is reached. The variations in retention found in a single sample are not the best test of the relation, since the variation in moisture in one sample varies a maximum of 30 per cent (Sample G 11). The evidence is even more striking when one considers the total variation in all samples: w ranges from 1.09 to 10.01 per cent, almost ten-fold, while the ratio w/s ranges from 2.96 to 4.84. This latter range includes samples collected under widely varying conditions, and therefore they are not comparable as far as equilibrium is concerned.

The w/s ratio for the two samples that drained 36 hours is 4.37, for the seven samples that drained 72 hours it is 3.62, and for the two lower divisions of the one sample that drained 13 days it is 2.99. Such rapid approach to equilibrium may seem anomalous, but when one considers the length of these columns, they are seen to represent only a fraction of the lengths drained in the laboratory experiments, and since equilibrium is reached first at the top of such a column, it may well be that approximate equilibrium was reached within 13 days. It is possible that evaporation loss affected the result slightly in this case, however.

(4) *Cylinders Driven, Material Saturated and Drained in Field.* This method is essentially similar to the first except that the materials were artificially saturated by pouring water to a height of about eight inches above the top of the ground surf[illegible] the [illegible]linder after driving it. This is a desirable check me[illegible]as it is not directly demonstrable that rainfall (Method 3) would reach every part of the sample. Parts which were below retention before the rain might not always reach retention. Enclosure of the sample in the cylinder and addition of a large excess of water is thought to obviate this possibility. In this method two cylinders were generally driven as close together as possible and attempts were made to drive them to equal depths in the same stratum. One cylinder was removed about 11 days after saturation and the other was not removed until about 22 days had elapsed. Concordance of the two results gives a measure of the sufficiency of the drainage period. The period of 11 days seems short, but it was believed sufficient for an approach to equilibrium with

coarse sediments in columns as short as these (6 to 8 inches) since the time of drainage to equilibrium increases very rapidly with length of column and is not in direct linear relation to it.

The cylinders were covered to minimize evaporation, but the steel became so warm at times that it was almost too warm to touch, and because of the high heat conductivity the temperature of the sample must have been considerably higher than normal. Undoubtedly there was appreciable evaporation loss in the longer periods. A few of the results obtained by this method are presented in Table 23.

TABLE 23

MOISTURE RETENTION DETERMINATIONS OF MATERIALS DRAINED IN FIELD

Sample G 14. Location G 20. Porosity 27.1%. Drainage period 11 days.

Division	1	2	3
m=Mean size in mm.	1.16	1.59	3.95
s=Surface factor	1.56	1.46	0.62
w=Moisture per cent	5.58	5.69	2.20
w/s	3.58	3.90	3.55

Averages: w=3.39±1.89; w/s=3.68±0.16.

Sample G 15. Location G 20. Porosity 24.1%. Drainage period 22 days.

Division	1	2	3
m=Mean size in mm.	1.95	3.01	3.74
s=Surface factor	1.45	1.10	0.68
w=Moisture per cent	2.97	2.69	1.65
w/s	2.05*	2.44*	2.43*

Averages: w=2.44±0.52; w/s=2.31±0.17.

*Probable evaporation loss.

Sample G 16. Location G 17. Porosity 27.3%. Drainage period 11 days. North exposure on face of steep cliff; little evaporation opportunity.

Division	1	2	3
m=Mean size in mm.	1.34	1.10	1.70
s=Surface factor	1.03	1.17	0.86
w=Moisture per cent	4.08	4.94	4.17
w/s	3.96	4.22	4.85

Averages: w=4.40±0.36; w/s=4.34±0.34.

Sample G 20. Location F 20. Porosity 48.0%. Drainage period (?). See below.

Division	1	2
m=Mean size in mm.	5.35	7.17
s=Surface factor	0.44	0.41
w=Moisture per cent	1.97	1.96
w/s	4.48	4.78

Averages: w=1.97±0.05; w/s=4.63±0.15.

The first experiment, following the outlined procedure of driving two cylinders side by side in similar material, shows the great difficulty of securing accurate control of results except in the most favorable circumstances. The material in Sample G 14 was allowed to drain 11 days; that in Sample G 15 a total of 22 days. It is evident from the results in the first case that percolation of excess water and attainment of near equilibrium conditions is a very slow process in poorly sorted deposits, since the relative retention after 11 days is about the same as it was in 36 hours in similar deposits when an excess of water was not used (Method 1).

One fact is obtained from the results with the first cylinder. Although the retention of one of the portions in the cylinder (Sample G 14) is 250 per cent of the retention in the other, the ratio w/s is essentially constant.

Concurrently with the placing of cylinders G 14 and G 15, another, G 17, was driven in a north exposure, where evaporation losses should have been much less. The regular increase in the ratio w/s, although the material in each division is quite similar, tends to show that percolation of water was slow and that drainage had not closely approached equilibrium after 11 days.

Although cylinder G 20 remained out 24 days, it can not be said that the material drained for this period. The cylinder was driven in the bank of a stream channel, and runoff from a late rain practically filled the channel for some days after the cylinder was driven. Estimation of drainage period therefore is impossible. It is believed, however, that even though the retention is only 2 per cent of the dry weight, drainage was not complete.

The apparent difficulty of attaining an approach to equilibrium in periods sufficiently short to preclude the danger of excessive evaporation losses led to the abandonment of this method of investigation. Graphical representation of the results appears later with the results of other determinations of specific retention.

An Indirect Method for Estimation of Specific Retention.

Plate XXIII shows graphically weight per cent moisture retentions plotted against computed surface factors for the determinations made by the four methods described in the preceding pages. All results which indicated possible evaporation losses were rejected. Presented in this form, the graph shows that the moisture retention increases with the surface factor, and although the spread of values is considerable, the relationship between the two factors appears to be roughly a straight line within the limits considered. If a straight line be drawn representing the approximate mean for the spread of values in Plate XXIII, the slope, or w/s ratio, will be about 3.5.

However, as pointed out in earlier discussions, the period of drainage was in many cases too short to permit moisture retention to reach or even closely approach equilibrium, and consequently the spread of values in the graph is probably due in large part to the excess water present in many samples. The mean value of 3.5 for w/s would, therefore, seem to be too high; the lower values in the graph probably represent more complete drainage. For this reason a straight line was drawn through the points at the lower limit of the spread of values shown on the graph, and this line with a slope of 3, was considered to represent the relationship (w/s) between moisture retention and surface factor when moisture retention has reached a practical equilibrium.

By the use of this relationship, a simple indirect method of calculating approximate specific retention for sands and gravels, from their mechanical analyses, is possible. The application is as follows:

$$w = 3\,s$$

and specific retention $= (w)\ (d)\ (100 - P)$

where w is the $\dfrac{\text{Wt. of water}}{\text{dry wt.}} \times 100$, s is the surface factor, d, the specific gravity of the solid, and P, the porosity of the sediment.

In order to estimate specific yield values for the various types of materials under consideration, the porosities of sands and gravels were determined directly for each sample by measurement. The specific retentions of these samples, however, were not measured directly, but were estimated from the mechanical analyses of the samples by application of the surface factor method outlined above. For finer materials, of which no mechanical analyses were made, both porosity and specific retention values were estimated directly from measurements.

Although the lower limit value (3) for w/s was thought to be a better value than the mean (3.5) for computation of specific retention, consideration of the resulting specific yield values for either case, shows that the difference is not significant except for the finer limit of materials computed.

TABLE 24

COMPARATIVE SPECIFIC YIELD VALUES FOR SANDS AND GRAVELS, USING S=3, AND S=3.5

Specific yield (per cent)

	Fine sand lower limit computed	Median of sands	Median of gravels	Coarsest gravels
s=3	24	31	17	13
s=3.5	21	29.7	16.3	12.5
Difference	3	1.3	0.7	0.5
Difference (per cent)	12.5	4.2	4.1	3.8

Table 24 gives the average specific yield values computed for various types of materials, using 3 for w/s, with the corresponding values using 3.5 for w/s. The differences are seen to range from 0.5 to 3 per cent yield. For the lower size limit computed (fine sand) the difference is 12.5 per cent of the value computed with w/s equal to 3. For the median of sands it is 4.2 per cent and slightly less for the coarser materials.

In view of the many uncertainties involved in the computation of groundwater storage capacity and storage changes, estimates at best can be only approximations, and therefore the differences cited above are not important except toward the lower size limit for which the w/s method of estimating specific retention was used. A relatively small portion of the materials studied are thus affected.

This paper has dealt with the methods and results of experimental work carried out to determine the water-yielding capacities of various types of sediments. In Chapter III, the application of these results to the various types of sediments occurring in the South Coastal Basin is made, and the various relationships that exist are discussed and evaluated for the purpose of classifying and assigning specific yield values to the materials reported in well logs.

APPENDIX II

MECHANICAL ANALYSES, POROSITIES AND COMPUTED SPECIFIC RETENTIONS OF CERTAIN SAMPLES OF ALLUVIAL AND MARINE MATERIALS IN SOUTH COASTAL BASIN *

Sample number	G1	G2	G4	G6	G7	G8	G9	G10	G11	G12	G13
Location number	J22	J22	F17	G17	G17	G17	G17	G17	F20	F20	G20
Diameter in millimeters	Percentages										
32–64	0.0	0.0	0.0	2.1	0.0	0.0	10.2	0.0	11.3	11.5	12.5
16–32	0.2	0.0	3.6	4.2	7.9	3.5	13.4	4.1	15.8	14.2	12.4
8–16	0.4	0.0	4.4	7.3	13.7	7.8	12.6	10.9	16.3	16.9	8.9
4– 8	0.7	0.3	5.1	9.9	9.1	4.7	6.4	9.4	11.5	9.0	9.1
2– 4	0.9	1.0	5.9	14.6	10.1	5.5	5.8	11.7	10.1	10.1	11.3
1– 2	4.0	4.9	11.9	20.3	13.4	11.3	10.5	17.5	12.8	14.0	14.4
½– 1	28.3	28.9	27.5	18.0	18.2	24.2	15.9	16.6	9.6	10.0	14.9
¼–½	46.1	48.3	27.6	13.5	17.6	26.6	14.6	16.8	7.5	9.1	10.2
⅛–¼	14.3	12.6	9.1	5.7	6.4	11.9	6.7	8.4	2.6	2.8	3.5
Less than ⅛	5.1	4.0	5.0	4.4	3.6	4.5	3.9	4.6	2.6	2.4	2.8
Mean size in mm.	0.41	0.41	0.78	1.45	1.56	0.82	2.47	1.28	4.25	3.91	3.06
Ratio deviation	2.08	1.90	3.65	4.22	4.79	3.99	6.65	4.36	5.37	5.52	5.83
Surface factor	1.87	1.77	1.44	1.04	1.03	1.44	0.97	1.17	0.59	0.62	0.73
Porosity per cent	39.9	41.0	37.6	35.7	35.6	30.9	31.2	34.4	27.6	28.6	23.2
Retention per cent	9.0	8.4	7.2	5.4	5.3	8.0	5.4	6.2	3.4	3.5	4.5
Specific yield per cent	30.9	32.6	30.4	30.3	30.3	22.9	25.8	28.2	24 2	25.1	18.7

Sample number	G14	G15	G16	G20	G21	G22	G27	G28	G29	G30	G31
Location number	G20	G20	G17	F20	G14	G14	G20	F21	E25	G20	H19
Diameter in millimeters	Percentages										
128–256	0.0	0.0	0.0	0.0	0.0	0.0	8.3	8.8	12.0	8.3	7.0
64–128	0.0	0.0	0.0	0.0	0.0	0.0	8.5	13.7	16.3	10.2	11.7
32– 64	4.3	13.0	0.0	10.1	0.0	0.0	16.8	17.8	23.2	18.8	18.3
16– 32	15.8	13.8	7.2	24.5	0.4	0.0	13.6	12.9	10.7	18.3	11.9
8– 16	14.4	13.7	7.3	22.0	1.0	0.1	10.2	7.9	7.0	9.4	9.7
4– 8	9.7	9.4	8.0	11.0	1.2	2.2	6.7	5.8	4.5	6.4	7.6
2– 4	7.6	7.1	10.3	10.6	0.9	5.2	5.2	4.9	4.3	4.7	5.1
1– 2	10.4	9.2	20.9	9.3	2.7	16.2	7.6	7.2	6.2	6.0	7.0
½– 1	13.8	13.1	22.9	7.0	11.3	26.4	11.3	8.6	5.0	7.4	8.9
¼– ½	11.1	11.0	15.3	4.1	42.3	30.9	7.5	6.4	5.1	6.6	7.7
⅛– ¼	7.4	4.4	3.9	1.3	31.0	11.0	2.5	2.8	2.6	2.3	2.9
Less than ⅛	5.5	5.3	4.2	2.1	9.2	8.0	1.8	3.2	3 1	1.6	2.2
Mean size in mm.	2.38	3.20	1.37	6.39	0.31	0.52	8.32	9.98	14.9	11.2	8.93
Ratio deviation	6.20	6.73	4.06	4.64	2.36	2.58	8.12	8.86	8.54	7.46	8.27
Surface factor	1.06	0.94	1.02	0.42	2.55	1.81	0.50	0.58	0.51	0.43	0.53
Porosity per cent	27.1	24.1	27.3	**48.0	**49.9	**47.3	16.6	18.1	14.2	14.9	12.9
Retention per cent	6.2	5.7	6.0	-------	-------	-------	3.4	3.8	3.5	2.9	4.7
Specific yield per cent	20.9	18.4	21.3	-------	-------	-------	13.2	14.3	10.7	12 0	8.2

*Sample locations are shown on Plate F, in pocket.

**Porosities abnormally high on account of being very recent deposits in stream channel.

Sample number	G32	G33	G34	G35	G36	G37	G38	G40	E41	G42	G43
Location number	H19	H19	H19	H19	H19	G20	G20	G16	E11	E11	E11
Diameter in millimeters	Percentages										
256–512	0.0	0.0	0.0	0.0	0.0	13.8	11.0	0.0	7.5	15.1	0.0
128–256	0.0	0.0	0.0	0.0	0.0	12.8	16.8	0.0	18.8	14.7	27.5
64–128	4.3	0.0	0.0	0.0	0.0	17.0	13.9	9.5	23.5	16.4	15.0
32– 64	5.4	7.0	0.0	1.6	8.4	16.7	12.4	18.4	10.3	9.7	9.8
16– 32	14.8	17.4	0.0	7.0	7.1	10.9	9.9	19.9	5.7	5.7	7.0
8– 16	15.7	8.1	0.2	7.8	6.6	5.9	6.7	14.9	4.4	5.6	6.2
4– 8	12.1	5.7	0.2	6.0	5.9	2.9	4.3	8.6	3.6	4.3	3.6
2– 4	10.6	3.8	0.3	4.2	5.3	2.6	3.1	4.7	3.2	5.8	5.6
1– 2	11.4	6.7	0.8	6.2	6.8	3.5	4.7	5.0	8.2	8.6	9.5
½– 1	10.8	10.9	7.2	10.6	16.1	5.6	6.0	5.3	6.1	7.0	7.0
¼– ½	10.6	16.8	36.5	31.3	29.7	5.0	7.1	6.2	4.4	3.8	4.4
⅛– ¼	2.8	11.3	36.5	17.6	10.2	2.0	2.5	2.7	1.3	1.4	1.8
Less than ⅛	1.5	12.3	18.4	7.6	3.9	1.3	1.6	4.8	1.0	1.9	2.6
Mean size in mm.	3.93	1.59	0.23	0.81	1.28	27.5	20.9	8.01	24.2	22.0	17.1
Ratio deviation	5.55	8.26	1.95	5.47	6.25	9.07	10.5	7.09	9.23	10.6	9.99
Surface factor	0.56	1.80	3.36	1.83	1.31	0.33	0.41	0.68	0.30	0.38	0.46
Porosity per cent	19.7	23.5	39.4	31.2	26.5	16.3	16.4	16.8	13.9	16.3	17.9
Retention per cent	3.6	11.1	16.4	10.1	7.7	2.2	2.7	4.5	2.1	2.6	3.0
Specific yield per cent	16.1	12.4	23.0	21.1	18.8	14.1	13.7	12.3	11.6	13.7	14.9

Sample number	G44	G45	G46	G47	G48	G50	G51	G52	G53	G54	G55
Location number	F11	F11	E11	E12	F12	F12	F14	F14	G12	G12	E11
Diameter in millimeters	Percentages										
128–256	15.6	9.6	11.6	0.0	0.0	4.8	0.0	0.0	0.0	0.0	0.0
64–128	12.8	16.0	12.5	11.4	2.3	17.8	2.2	0.0	4.2	8.7	1.9
32– 64	17.9	13.1	19.5	14.2	11.1	14.4	5.6	2.3	6.8	3.8	8.7
16– 32	10.8	9.9	13.0	14.9	8.7	14.3	4.9	4.3	7.4	11.3	14.2
8– 16	7.8	6.4	8.8	13.5	8.4	10.3	3.6	6.1	10.5	10.9	11.4
4– 8	6.7	4.4	4.6	10.4	4.4	5.6	4.7	8.0	10.9	12.9	10.6
2– 4	5.4	7.0	5.4	10.2	7.1	5.7	10.4	12.7	4.9	9.1	5.4
1– 2	6.1	12.3	7.7	10.1	14.0	8.8	22.8	21.1	11.7	15.3	9.6
½– 1	6.3	9.9	7.3	7.1	19.6	7.6	25.8	23.7	14.1	6.8	10.2
¼– ½	6.5	6.7	5.5	4.8	16.1	6.9	15.6	16.7	18.2	17.0	11.6
⅛– ¼	2.7	2.7	2.0	1.9	5.2	2.4	3.4	3.2	6.0	4.4	7.9
Less than ⅛	1.4	2.0	2.1	1.5	3.1	1.4	1.0	1.9	5.3	3.7	11.4
Mean size in mm.	13.7	8.80	12.4	7.60	2.24	10.1	1.63	1.43	2.10	2.82	2.12
Ratio deviation	8.49	9.94	8.14	5.92	6.57	7.66	4.64	3.83	6.88	6.75	7.94
Surface factor	0.41	0.52	0.45	0.40	0.92	0.43	0.77	0.84	1.12	0.88	1.55
Porosity per cent	15.6	21.0	16.5	17.5	27.4	19.4	29.6	40.4	37.4	20.5	24.2
Retention per cent	2.8	3.3	3.0	2.7	5.4	2.8	4.4	4.0	5.6	9.5	3.0
Specific yield per cent	12.8	18.7	13.5	14.8	22.0	16.8	25.2	36.4	31.8	14.9	14.7

Sample number	G58	G59	G60	G61	G62	G63	G64	G65	G66	G67
Location number	G18	N17	N17	N17	N17	N17	N17	N17	N17	F13
Diameter in millimeters	Percentages									
128–256	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.3
64–128	2.3	1.3	7.2	2.4	2.9	2.4	1.2	7.2	5.1	6.8
32– 64	5.9	8.5	11.8	7.2	5.2	9.5	10.1	18.7	17.8	4.4
16– 32	12.7	15.0	13.9	15.6	16.5	19.4	17.4	23.9	23.6	3.7
8– 16	12.4	14.3	10.9	15.2	16.9	16.6	17.2	19.0	16.8	4.8
4– 8	2.8	9.2	8.1	12.1	12.8	9.2	11.0	10.3	10.8	4.2
2– 4	3.8	6.6	5.7	11.4	11.8	7.1	8.4	5.0	7.7	9.7
1– 2	9.3	8.7	8.0	10.4	11.5	12.5	10.9	2.9	5.0	17.3
½– 1	16.7	13.9	14.7	8.0	8.7	11.7	7.2	2.6	3.3	14.9
¼– ½	17.0	15.4	12.8	11.1	6.1	8.5	13.1	4.4	4.1	10.1
⅛– ¼	8.3	5.0	4.9	4.8	5.3	2.1	2.3	3.4	3.3	1.7
Less than ⅛	8.7	2.1	2.0	1.8	2.3	1.0	1.2	2.6	2.5	5.1
Mean size in mm.	1.74	3.04	3.48	3.79	4.04	4.78	4.42	10.1	8.70	4.58
Ratio deviation	7.54	6.29	7.17	5.73	5.47	5.45	5.55	5.60	5.53	11.0
Surface factor	1.46	0.76	0.71	0.63	0.62	0.47	0.53	0.47	0.47	0.86
Porosity per cent	26.0	18.9	17.4	26.5	23.5	24.5	20.0	25.3	27.7	25.7
Retention per cent	8.7	5.0	4.7	3.7	3.8	2.9	3.4	2.8	2.7	5.1
Specific yield per cent	17.3	13.9	12.7	22.8	19.8	21.6	16.6	22.5	25.0	20.6

Sample number	G68	G69	G70	G71	G73	G74	G75	G76	G77	G79	G80
Location number	F13	F12	F12	G27	G27	G27	F27	F27	G20	F26	F26
Diameter in millimeters	Percentages										
128–256	6.5	0.0	0.0	0.0	0.0	0.0	5.0	3.7	0.0	0.0	0.0
64–128	6.4	8.4	7.2	3.6	8.0	3.2	5.6	12.9	6.5	17.5	18.2
32– 64	7.3	10.7	13.6	15.5	11.0	12.9	15.0	18.4	24.4	23.1	21.7
16– 32	7.8	14.5	12.9	16.5	11.4	15.3	13.1	14.9	17.7	14.5	12.7
8– 16	6.1	11.9	10.8	15.4	13.9	11.8	10.0	9.0	11.0	8.7	8.5
4– 8	8.5	7.2	7.9	9.8	8.9	7.0	5.2	5.1	6.4	5.2	3.4
2– 4	16.9	7.9	8.4	6.1	8.3	7.1	4.8	3.7	5.8	4.2	5.1
1– 2	16.5	12.0	12.9	7.5	12.4	11.7	7.4	5.1	7.2	6.5	7.6
½– 1	10.0	11.8	14.0	8.2	13.0	14.9	13.5	7.4	8.3	8.0	9.9
¼– ½	6.3	9.8	8.7	9.7	8.9	11.4	15.3	9.5	7.6	7.9	8.3
⅛– ¼	4.4	3.6	2.3	3.4	2.7	3.1	2.1	6.1	3.1	2.5	2.6
Less than ⅛	3.4	2.2	1.3	4.3	1.5	1.6	3.0	4.1	2.0	1.9	1.9
Mean size in mm.	4.12	4.56	4.79	4.99	4.64	3.48	4.88	7.21	7.60	9.87	8.83
Ratio deviation	7.57	6.92	6.45	6.93	6.36	6.41	8.58	9.59	6.82	7.55	7.96
Surface factor	0.72	0.63	0.52	0.76	0.55	0.61	0.73	0.79	0.52	0.48	0.51
Porosity per cent	26.4	22.8	22.8	16.3	18.5	24.3	19.1	17.8	16.7	16.1	16.5
Retention per cent	4.3	3.9	3.2	5.1	3.6	3.7	4.7	5.2	3.5	3.2	3.4
Specific yield per cent	22.1	18.9	21.6	11.2	14.9	20.6	14.4	12.6	13.2	12.9	13.1

Sample number Location number	G81 F26	G83 E25	G84 E25	G85 E25	G86 E25	G87 G27	G88 G27	G90 G30	G91 G29	G92 G29	G93 G29
Diameter in millimeters	Percentages										
128–256	8.6	14.0	7.7	2.5	15.7	0.0	0.0	0.0	0.0	0.0	0.0
64–128	11.6	21.1	16.4	6.6	24.6	2.1	3.4	13.4	0.0	0.0	0.0
32– 64	16.4	14.9	16.3	14.7	14.1	4.9	8.0	19.2	5.4	1.6	0.4
16– 32	14.9	9.4	11.5	13.2	8.4	8.6	15.2	8.1	4.6	3.0	2.1
8– 16	10.4	7.7	9.6	9.5	5.8	8.7	14.7	4.1	3.6	3.0	3.1
4– 8	5.9	5.0	6.4	5.5	2.7	5.9	8.8	5.8	5.5	3.3	4.0
2– 4	5.4	4.5	5.2	5.2	4.1	9.2	9.1	6.5	5.5	4.3	5.1
1– 2	7.2	5.7	6.9	8.9	5.9	15.1	13.8	14.7	14.0	13.7	15.9
½– 1	9.5	6.6	8.1	14.5	6.7	17.7	12.3	16.8	23.8	29.7	29.4
¼– ½	7.3	5.7	6.9	11.8	6.4	15.3	9.3	7.5	25.6	27.9	28.5
⅛– ¼	1.9	3.3	2.6	4.1	2.8	9.2	3.2	2.5	8.9	9.8	7.7
Less than ⅛	0.9	2.1	2.4	3.5	2.8	3.3	2.1	1.3	3.1	3.7	3.8
Mean size in mm	10.3	14.7	10.4	4.39	15.9	1.73	3.82	5.46	1.06	0.76	0.75
Ratio deviation	7.63	9.08	8.45	8.35	9.86	5.87	5.85	7.72	4.76	3.59	3.20
Surface factor	0.39	0.47	0.51	0.79	0.52	1.05	0.62	0.53	1.22	1.38	1.34
Porosity per cent	14.5	13.1	15.9	20.6	16.1	27.6	14.6	22.5	30.0	32.9	34.0
Retention per cent	2.7	3.3	3.4	5.0	3.5	6.1	44.3	3.3	6.9	7.4	7.1
Specific yield per cent	11.8	9.8	12.5	15.6	12.6	21.5	10.3	19.2	23.1	25.5	26 9

Sample number Location number	G94 G29	G95 G29	G96 G29	G97 G29	G98 F17	G99 F17	G100 C3	G101 D3	G102 B6	G104 G14	G106 G14
Diameter in millimeters	Percentages										
128–256	0.0	0.0	0.0	0.0	4.3	0.0	15.1	0.0	9.0	3.3	0.0
64–128	0.0	0.0	0.0	0.0	10.9	19.5	5.7	0.0	15.7	7.9	1.0
32– 64	0.0	0.0	1.6	0.4	13.1	19.8	9.2	4.8	17.8	18.5	13.0
16– 32	1.6	0.9	4.3	1.1	14.0	12.5	17.2	7.5	12.3	17.1	18.0
8– 16	1.9	2.0	3.2	0.7	11.4	8.6	16.5	13.0	6.8	12.2	13.0
4– 8	1.8	4.4	2.9	1.0	8.0	6.9	9.0	9.6	4.8	8.3	9.2
2– 4	5.0	4.5	4.5	2.7	7.9	6.8	6.5	15.8	5.5	5.6	7.3
1– 2	14.3	13.1	11.1	11.2	8.5	7.3	6.0	16.1	9.9	5.4	11.8
½– 1	30.0	27.8	24.2	22.8	9.4	7.9	4.6	15.0	8.9	5.1	13.9
¼– ½	32.6	33.1	37.1	44.4	8.5	7.3	6.1	13.2	5.2	8.4	8.8
⅛– ¼	9.1	9.7	8.7	12.4	2.5	2.1	2.4	3.0	2.4	6.0	2.5
Less than ⅛	3.7	4.5	2.4	3.1	1.5	1.3	1.7	2.0	1.7	2.2	1.5
Mean size in mm	0.63	0.62	0.76	0.51	7.22	9.74	11.1	2.29	11.1	7.54	4.37
Ratio deviation	2.80	2.89	3.74	2.56	7.40	7.19	7.38	4.64	8.24	7.77	5.78
Surface factor	1.43	1.51	1.33	1.60	0.49	0.42	0.41	0.71	0.44	0.61	0.54
Porosity per cent	33.7	31.5	33.3	36.8	15.1	17.5	19.7	25.5	13.5	21.1	19.3
Retention per cent	7.6	8.3	7.1	8.1	3.3	2.8	2.6	4.3	3.2	3.9	3.5
Specific yield per cent	26.1	23.2	26.2	28.7	11.8	14.7	17.3	21.2	10.3	17.2	15.8

Sample number	G107	G108	G109	G110	G111	G112	G113	G114	G115	G116	G117
Location number	G14	G14	G14	H14	H14	H14	H14	H14	H14	H13	H13
Diameter in millimeters	Percentages										
64–128	2.5	3.5	8.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.8
32– 64	17.0	14.7	15.0	0.0	0.0	0.0	0.0	0.0	0.0	4.9	5.0
16– 32	16.1	10.9	12.3	0.0	0.0	0.1	1.0	7.1	1.8	9.5	7.2
8– 16	12.6	7.9	9.2	0.0	0.1	0.7	0.9	5.4	1.8	10.4	6.7
4– 8	8.4	5.8	4.8	0.0	0.4	0.6	1.1	5.9	1.9	4.8	5.6
2– 4	5.1	6.0	4.5	0.1	0.5	0.6	1.2	5.6	2.2	9.8	8.3
1– 2	8.4	11.7	8.8	0.2	1.9	2.1	2.8	11.5	6.0	13.1	12.4
½– 1	12.3	21.0	16.8	1.8	10.8	8.4	11.0	18.6	23.9	19.9	18.8
¼– ½	11.9	14.3	15.7	27.5	46.1	36.8	45.6	31.1	52.7	22.1	21.4
⅛– ¼	3.6	3.2	2.7	49.7	30.0	26.2	23.2	5.9	7.7	2.9	5.5
Less than ⅛	2.1	1.0	1.4	20.7	10.2	24.5	13.2	2.9	2.0	2.6	4.3
Mean size in mm	4.55	3.16	4.19	0.19	0.28	0.24	0.32	1.25	0.53	1.74	1.70
Ratio deviation	6.80	6.72	7.78	1.69	1.94	2.32	2.55	5.31	2.60	5.19	6.42
Surface factor	0.65	0.66	0.65	3.79	2.65	3.56	2.68	1.15	1.48	0.91	1.11
Porosity per cent	13.5	22.1	19.7	39.7	42.2	45.3	45.1	28.8	38.6	30.5	25.7
Retention per cent	4.5	4.1	4.2	18.2	12.2	15.5	11.7	6.5	7.3	5.0	6.6
Specific yield per cent	9.0	18.0	15.5	21.5	30.0	29.8	33.4	22.3	31.3	25.5	19.1

Sample number	G118	G119	G120	G121	G122	G123
Location number	G13	G13	F15	F15	C6	C6
Diameter in millimeters	Percentages					
128–256	0.0	0.0	11.9	10.9	7.6	0.0
64–128	0.0	4.1	9.8	19.8	16.0	7.0
32– 64	1.8	1.8	24.1	19.5	18.2	9.5
16– 32	2.7	3.7	12.5	13.3	11.1	11.7
8– 16	3.7	3.1	8.6	7.6	7.8	9.9
4– 8	3.9	3.7	4.8	5.7	5.7	10.1
2– 4	5.7	3.8	4.1	3.4	7.1	9.2
1– 2	14.3	7.5	6.0	4.6	7.6	12.1
½– 1	26.8	18.2	7.8	5.9	7.2	13.6
¼– ½	34.1	42.0	6.8	6.1	6.5	10.7
⅛– ¼	6.0	10.0	2.1	2.1	3.1	4.4
Less than ⅛	1.0	2.1	1.5	1.1	2.1	1.8
Mean size in mm	0.85	0.86	12.9	15.6	10.5	3.83
Ratio deviation	3.48	5.13	8.03	7.55	8.40	6.62
Surface factor	1.11	1.36	0.41	0.35	0.50	0.66
Porosity per cent	39.1	42.6	16.3	12.2	14.3	17.7
Retention per cent	5.4	6.2	2.8	2.5	3.6	4.6
Specific yield per cent	33.7	36.4	13.5	9.7	10.7	13.1

Sample number	G145	G146	G149	G150	G151	G152	G153	G154	G155	G156
Location number	C7	C4	C7	C7	C7	C7	D7	D7	D5	D5
Diameter in millimeters	Percentages									
128–256	0.0	0.0	11.5	4.6	24.8	5.1	6.1	6.2	0.0	0.0
64–128	13.2	5.2	11.7	12.6	12.5	8.6	7.3	4.2	6.6	0.0
32– 64	18.8	6.7	17.1	14.4	18.5	15.7	14.7	4.9	9.8	1.1
16– 32	10.8	17.8	10.7	14.0	11.0	14.1	13.1	8.9	9.7	2.7
8– 16	7.1	21.2	7.3	11.6	6.2	12.0	8.3	8.8	8.7	4.3
4– 8	5.5	10.5	5.8	8.2	3.1	9.3	6.5	10.2	5.8	6.8
2– 4	6.6	6.3	4.9	6.2	2.7	8.2	4.6	9.1	7.2	7.9
1– 2	10.3	7.9	8.2	7.3	4.9	9.7	8.9	12.7	12.8	13.2
½– 1	12.0	6.2	9.2	9.1	6.9	7.0	12.3	15.1	12.9	17.7
¼– ½	10.3	7.9	7.5	8.0	4.5	4.3	12.2	13.8	13.4	22.6
⅛– ¼	3.5	6.3	4.1	2.5	3.5	4.1	3.9	4.3	10.2	14.4
Less than ⅛	1.9	6.1	2.0	1.5	1.4	1.9	2.1	1.8	2.9	9.3
Mean size in mm.	4.84	4.33	10.8	8.26	19.8	7.98	5.58	3.29	2.65	0.74
Ratio deviation	8.06	7.19	9.63	7.50	9.43	7.10	8.77	7.44	7.72	4.32
Surface factor	0.60	0.95	0.55	0.47	0.40	0.49	0.66	0.72	0.97	1.82
Porosity per cent	16.5	28.6	12.7	16.3	15.1	21.7	19.0	23.2	25.2	35.2
Retention per cent	4.2	6.8	3.9	3.2	2.7	3.1	4.3	4.4	6.1	9.9
Specific yield per cent	12.3	21.8	8.9	13.1	12.4	18.6	14.7	18.8	19.1	25.3

Sample number	G159	G160	G161	G162	G163	G164	G165	G171	G175	G176	G177
Location number	E7	E7	E7	F5	E5	D5	D5	F15	G16	G16	G16
Diameter in millimeters	Percentages										
128–256	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.5	0.0	0.0	0.0
64–128	4.2	0.0	0.0	0.0	5.2	0.0	3.3	15.9	0.0	8.8	1.4
32– 64	6.3	4.0	5.3	0.4	5.8	5.0	5.2	19.1	1.7	17.1	15.2
16– 32	6.8	3.4	3.8	3.4	21.4	10.2	15.1	15.9	9.1	13.0	17.1
8– 16	6.4	3.7	4.1	8.5	17.4	16.9	15.6	8.9	14.3	13.8	14.3
4– 8	5.6	3.2	4.1	9.3	9.6	13.8	9.2	4.3	6.8	6.9	7.6
2– 4	6.4	6.6	7.4	10.6	9.0	12.2	10.4	3.8	10.7	7.4	8.1
1– 2	9.6	15.9	17.5	13.0	6.5	12.3	10.1	4.6	14.2	6.9	7.6
½– 1	14.7	28.1	25.8	23.7	4.1	9.4	13.6	6.8	14.8	8.5	9.4
¼– ½	21.4	28.4	24.4	22.0	8.0	5.4	11.5	6.9	19.2	11.0	12.2
⅛– ¼	11.6	3.7	3.8	6.7	5.6	8.1	3.4	2.2	5.4	3.9	4.2
Less than ⅛	7.0	3.0	3.8	2.4	7.4	6.7	2.6	1.1	3.8	2.7	2.9
Mean size in mm.	1.42	0.95	1.14	1.17	4.28	2.55	3.36	14.5	1.71	5.66	4.32
Ratio deviation	7.28	3.98	4.44	3.94	7.35	5.82	5.89	7.69	5.07	7.48	6.71
Surface factor	1.48	1.13	1.13	1.05	1.03	1.08	0.70	0.37	1.01	0.66	0.72
Porosity per cent	26.1	32.8	37.5	38.2	19.6	24.5	23.2	14.0	31.1	16.3	19.8
Retention per cent	8.8	6.1	5.7	4.9	6.6	6.6	4.3	2.6	5.6	4.4	4.6
Specific yield per cent	17.4	26.7	31.8	33.3	13.0	17.9	18.9	11.4	25.5	11.9	15.2

Sample number	G178	G179	G180	G181	G182	G183	G184	G185	G186	G187	G188
Location number	G30	C8	C7	B6	G30	G29	G29	G29	G29	E28	E28
Diameter in millimeters	Percentages										
256–512	0.0	10.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
128–256	12.2	11.0	1.0	2.2	18.6	0.0	0.0	0.0	0.0	0.0	0.0
64–128	17.3	8.9	12.3	16.4	20.3	8.4	11.2	0.0	0.0	8.8	4.0
32– 64	10.4	16.0	21.5	16.5	16.7	13.1	11.7	1.2	0.0	2.5	7.7
16– 32	20.6	13.4	16.9	12.2	6.9	8.6	9.0	0.6	0.6	5.8	10.0
8– 16	5.3	7.5	9.8	9.3	3.3	8.8	8.9	2.7	1.7	8.5	9.7
4– 8	4.3	3.5	5.5	8.2	2.2	8.7	8.8	5.1	2.3	11.8	7.1
2– 4	3.8	5.3	6.3	7.6	2.6	10.8	10.0	8.3	6.5	16.0	12.9
1– 2	7.2	5.4	8.7	9.7	6.2	15.8	13.7	19.0	22.5	22.0	22.4
½– 1	8.6	6.8	8.4	8.0	9.9	10.3	10.7	31.0	32.0	14.4	15.2
¼– ½	6.5	6.9	6.4	6.5	9.0	10.9	10.8	25.2	20.0	6.7	7.3
⅛– ¼	2.4	3.2	2.7	2.3	2.9	3.3	3.7	5.5	13.1	2.0	2.1
Less than ⅛	1.4	1.9	1.5	1.1	1.4	1.3	1.5	1.4	1.3	1.5	1.6
Mean size in mm.	12.8	15.2	8.59	8.86	14.7	4.22	4.88	0.89	0.72	3.11	3.16
Ratio deviation	9.52	10.7	6.85	7.12	12.0	6.66	7.08	3.00	2.63	5.16	5.30
Surface factor	0.42	0.47	0.45	0.41	0.47	0.57	0.59	1.04	1.21	0.55	0.57
Porosity per cent	21.6	19.1	20.0	15.8	20.4	26.4	19.6	43.0	41.7	30.9	30.1
Retention per cent	2.6	5.7	2.9	2.9	3.0	3.4	3.8	4.7	5.6	3.1	3.2
Specific yield per cent	19.0	13.4	17.1	12.9	17.4	23.0	15.8	38.3	36.1	27.8	26.9

Sample number	G189	G190	G191	G192	G193	G194	G195	G196	G197	G198
Location number	F28	F28	F28	F28	H28	H28	J24	J24	J22	J22
Diameter in millimeters	Percentages									
64–128	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	4.6	0.0
32– 64	0.5	0.0	0.0	0.0	6.8	0.5	0.0	0.0	5.9	6.3
16– 32	1.1	1.1	0.2	0.1	9.4	5.5	0.4	3.8	10.6	18.3
8– 16	0.7	0.5	1.0	1.0	8.3	10.2	0.6	4.5	8.7	17.1
4– 8	2.0	1.2	2.5	3.4	7.3	14.0	1.2	4.2	7.4	7.1
2– 4	5.7	4.1	9.3	8.4	10.2	16.5	3.0	6.0	7.7	9.1
1– 2	17.1	11.3	29.6	30.2	16.7	26.7	15.2	16.2	13.2	15.7
½– 1	22.1	22.1	32.4	31.2	18.7	16.5	40.8	25.9	24.8	15.8
¼– ½	35.2	37.1	18.6	19.4	16.5	6.4	25.1	23.9	10.6	6.5
⅛– ¼	10.7	16.7	4.2	3.6	3.6	2.6	10.2	12.1	5.2	2.1
Less than ⅛	4.9	5.9	2.2	2.1	1.1	1.1	3.5	3.4	1.3	2.0
Mean size in mm.	0.59	0.47	0.85	0.86	2.20	2.12	0.59	0.81	2.48	3.63
Ratio deviation	2.86	2.65	2.39	2.41	5.33	3.41	2.32	3.62	5.99	5.08
Surface factor	1.57	1.85	1.02	1.01	0.72	0.57	1.42	1.35	0.73	0.57
Porosity per cent	39.8	40.6	39.6	40.7	27.6	30.4	41.4	27.7	33.2	24.4
Retention per cent	7.6	8.8	5.8	4.8	4.1	3.2	6.5	7.8	3.9	3.5
Specific yield per cent	32.2	31.8	33.8	35.9	23.5	27.2	34.9	19.9	29.3	20.9

Sample number	G215	G216	G217	G218	G219	G220	G221	G222	G223	G224	G225
Location number	H27	H27	I26	I26	M23	M23	N24	N24	O25	O25	G10
Diameter in millimeters	Percentages										
64–128	3.4	1.1	1.2	0.0	0.0	0.0	0.0	1.9	6.4	1.4	5.5
32– 64	8.1	9.1	4.0	4.9	3.3	2.3	5.9	5.9	13.5	8.3	3.1
16– 32	15.0	13.8	10.0	6.4	6.9	5.5	9.8	12.1	7.8	7.1	7.9
8– 16	14.9	18.3	15.6	11.9	7.5	7.2	11.4	15.9	6.9	5.3	7.3
4– 8	9.3	12.7	15.2	16.3	13.9	11.8	15.0	13.7	12.1	11.6	4.6
2– 4	9.6	10.0	11.1	17.2	15.3	13.5	9.4	12.8	17.0	15.0	5.3
1– 2	15.5	12.5	10.7	15.6	18.8	19.5	11.3	11.6	16.0	21.5	11.5
½– 1	10.1	7.4	11.9	13.3	13.9	22.9	15.2	10.5	10.3	16.6	18.3
¼– ½	11.2	8.4	12.5	9.5	15.7	13.1	15.1	9.6	6.7	9.3	26.5
⅛– ¼	1.7	5.7	5.2	2.9	3.1	2.8	4.7	3.6	2.0	2.5	8.4
Less than ⅛	1.2	2.0	2.6	2.0	1.6	1.4	2.2	2.4	1.3	1.4	1.6
Mean size in mm.	4.03	3.90	2.68	2.58	1.98	1.73	2.36	3.41	4.41	2.53	1.55
Ratio deviation	5.51	5.61	4.34	4.26	3.90	5.27	5.30	5.67	4.78	6.38	6.20
Surface factor	0.52	0.64	0.77	0.64	0.72	0.72	0.78	0.65	0.48	0.61	1.04
Porosity per cent	25.6	21.6	24.6	31.2	36.5	32.8	28.5	27.9	25.9	25.9	32.3
Retention per cent	3.1	4.0	4.7	3.5	3.7	3.9	4.5	3.8	2.9	3.6	5.7
Specific yield per cent	22.5	17.6	19.9	27.7	32.8	28.9	24.0	24.1	23.0	22.3	27.6

Sample number	G226	G227	G228	G229	G230	G231	G232	G235	*G236	*G237	*G238
Location number	G10	H10	I10	I10	I10	G30	G30	I10	P14	P14	P13
Diameter in millimeters	Percentages										
128–256	0.0	0.0	0.0	0.0	0.0	23.4	16.2	0.0	0.0	0.0	0.0
64–128	0.0	19.2	3.9	0.0	0.0	11.4	16.1	0.0	0.0	0.0	0.0
32– 64	9.1	16.7	7.6	0.7	0.0	18.4	16.9	0.9	1.1	0.3	11.9
16– 32	11.0	16.0	7.8	2.3	2.6	11.4	10.9	2.9	10.0	3.3	15.8
8– 16	8.9	11.6	7.6	3.4	3.3	6.9	8.7	5.4	16.5	10.1	11.0
4– 8	5.6	7.0	8.9	3.0	2.8	4.1	5.6	7.2	14.1	17.1	8.7
2– 4	5.8	6.5	7.4	5.8	4.9	3.9	4.6	12.3	14.2	21.2	7.7
1– 2	10.4	8.3	12.3	12.6	11.4	6.1	6.1	25.3	18.7	26.0	11.5
½– 1	16.9	7.0	10.5	21.0	11.4	7.3	6.9	27.7	15.1	14.6	16.2
¼– ½	24.8	4.5	24.7	31.5	44.2	4.9	4.9	12.8	6.4	3.8	11.7
⅛– ¼	5.2	1.9	6.8	16.9	17.1	1.4	1.8	1.5	1.8	1.7	3.5
Less than ⅛	2.3	1.3	2.5	2.8	2.3	0.8	1.3	4.0	2.1	1.9	2.0
Mean size in mm.	1.89	10.6	2.00	0.65	0.58	19.4	16.2	1.28	2.74	2.23	3.31
Ratio deviation	6.20	6.42	6.69	3.47	3.31	7.69	7.96	3.40	4.04	3.14	6.00
Surface factor	0.96	0.36	0.99	1.51	1.60	0.29	0.35	0.95	0.58	0.56	0.68
Porosity per cent	30.4	20.0	28.4	39.8	39.5	19.7	14.1	35.2	27.2	30.6	24.6
Retention per cent	5.4	2.3	5.7	7.3	7.8	1.9	2.4	4.9	3.4	3.1	4.1
Specific yield per cent	25.0	17.7	22.7	32.5	31.7	17.8	11.7	30.3	23.8	27.5	20.5

*Marine material.

Sample number	*G239	*G240	*G241	G242	G243	G244	*G245	*G246	*G247	*G248
Location number	P13	Q15	Q15	L22	M22	M22	J6	J6	J6	J6
Diameter in millimeters	Percentages									
128–256	0.0	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0.0	0.0
64–128	0.0	0.0	4.1	8.5	5.2	0.0	0.0	0.0	0.0	2.9
32– 64	4.6	0.4	5.0	15.8	18.1	9.4	0.9	3.7	9.1	9.3
16– 32	13.2	16.7	11.7	15.3	20.9	16.0	8.4	32.6	23.2	15.8
8– 16	14.9	21.9	18.5	12.1	17.9	16.5	17.3	20.8	19.0	16.1
4– 8	11.7	12.9	13.0	9.7	10.7	14.8	16.8	10.5	13.5	14.0
2– 4	12.8	9.7	13.4	7.4	8.2	8.6	12.3	7.6	8.0	9.6
1– 2	15.4	11.7	8.9	6.9	6.1	11.7	15.5	11.6	6.7	7.3
½– 1	15.6	12.7	11.0	8.2	4.0	7.6	12.7	11.0	7.1	6.2
¼– ½	8.4	10.7	8.3	8.0	3.0	7.5	13.3	8.6	10.3	13.2
⅛– ¼	2.3	2.2	3.3	4.5	1.4	4.0	1.9	2.3	1.2	4.5
Less than ⅛	1.1	1.2	4.8	3.6	2.2	3.9	0.9	1.3	1.9	1.1
Mean size in mm.	3.10	3.34	3.54	5.74	9.97	3.96	2.59	4.27	5.33	4.36
Ratio deviation	4.57	4.53	5.97	7.36	5.23	6.16	4.87	4.88	5.08	5.88
Surface factor	0.54	0.54	0.81	0.70	0.38	0.73	0.56	0.50	0.49	0.57
Porosity per cent	22.2	22.7	20.3	21.4	28.3	25.5	21.3	23.0	15.8	21.3
Retention per cent	3.4	3.4	5.2	4.4	2.2	4.4	3.5	3.1	3.3	4.4
Specific yield per cent	18.8	19.3	15.1	17.0	26.1	21.1	18.8	19.9	12.5	16.9

Sample number	*G250	*G251	*G252	*G253	G254	G255	G256	G257
Location number	N11	N11	N11	N11	M17	M17	L17	L17
Diameter in millimeters	Percentages							
64–128	0.0	0.0	0.0	0.0	2.3	1.0	0.0	0.0
32– 64	6.7	0.0	7.2	4.8	6.0	3.5	3.1	8.0
16– 32	12.8	4.0	15.9	8.4	10.7	7.6	20.8	19.3
8– 16	17.2	12.5	21.3	21.2	20.0	18.0	14.1	11.1
4– 8	8.2	13.8	13.5	15.5	21.6	16.2	10.2	9.1
2– 4	4.6	8.2	8.9	10.0	14.9	17.1	11.6	11.7
1– 2	15.9	13.5	12.3	13.9	10.7	12.4	15.1	13.9
½– 1	12.0	17.2	6.0	7.5	6.9	12.7	12.7	17.0
¼– ½	15.7	20.8	7.6	9.7	4.7	7.9	9.9	8.4
⅛– ¼	5.8	7.5	5.6	7.2	1.1	2.1	1.8	1.1
Less than ⅛	1.1	2.5	1.7	1.8	1.1	1.5	0.7	0.4
Mean size in mm.	2.68	1.39	4.12	2.96	4.95	3.17	3.54	3.78
Ratio deviation	5.65	4.34	5.19	5.04	4.08	2.98	2.95	2.31
Surface factor	0.72	1.01	0.59	0.70	0.37	0.53	0.48	0.44
Porosity per cent	24.3	28.4	18.0	30.1	30.5	31.3	24.1	27.1
Retention per cent	4.4	5.8	3.9	3.9	2.1	2.9	2.9	2.6
Specific yield per cent	19.9	22.6	14.1	26.2	28.4	28.4	21.2	24.5

*Marine material.

Sample number	G279	G280	G281	G282	G283	G284	G285	G286
Location number	M17	M17	M17	M17	F25	F25	G 25	G25
Diameter in millimeters	Percentages							
128–256	0.0	0.0	0.0	0.0	0.0	4.7	5.1	0.0
64–128	0.9	2.4	2.6	2.8	9.8	7.1	8.1	20.9
32– 64	15.7	10.1	20.7	20.6	21.9	16.3	16.8	11.4
16– 32	12.2	14.4	14.1	11.2	14.0	24.4	20.0	18.1
8– 16	15.0	13.8	9.2	9.3	10.8	11.0	16.0	13.3
4– 8	11.9	9.9	6.7	5.7	5.1	5.2	9.7	8.0
2– 4	10.6	11.7	7.2	8.4	7.6	4.8	5.9	6.9
1– 2	14.2	16.0	11.9	12.6	8.5	7.6	4.5	6.9
½– 1	10.3	12.8	14.7	15.2	9.2	9.4	4.0	5.2
¼– ½	4.9	4.9	10.2	11.8	7.8	6.7	5.1	4.7
⅛– ¼	1.8	1.7	2.0	1.9	2.9	1.6	2.8	2.5
Less than ⅛	2.5	2.3	0.7	0.5	2.4	1.2	2.0	2.1
Mean size in mm	4.82	4.24	4.92	4.46	7.03	9.22	10.6	10.4
Ratio deviation	5.36	5.29	6.38	6.44	7.26	6.65	6.30	6.60
Surface factor	0.53	0.54	0.48	0.50	0.56	0.39	0.43	0.44
Porosity per cent	26.1	22.5	21.7	24.8	18.7	15.6	23.5	20.3
Retention per cent	3.1	3.3	3.0	3.0	3.6	2.6	2.6	2.8
Specific yield per cent	23.0	19.2	18.7	21.8	15.1	13.0	20.9	17.5

Sample number	G287	G288	G289	G290	G291	G292	G293	G294	G295	G296	G297
Location number	H24	H24	H24	H24	H24	H24	F23	F23	F23	F23	F23
Diameter in millimeters	Percentages										
128–256	0.0	0.0	0.0	0.0	0.0	0.0	9.6	15.0	11.3	12.0	0.0
64–128	9.5	7.3	0.0	0.0	0.0	0.0	10.1	14.2	10.1	7.6	10.2
32– 64	13.4	18.4	3.1	2.7	3.7	0.7	20.1	18.9	20.0	19.3	18.5
16– 32	14.3	18.4	7.6	12.2	6.9	7.8	17.2	14.2	14.2	16.8	17.0
8– 16	11.9	14.9	11.3	13.0	9.4	16.2	10.8	7.6	9.3	10.4	9.7
4– 8	9.1	9.9	9.9	10.2	13.4	16.3	7.2	4.2	6.2	8.1	7.0
2– 4	7.5	6.1	8.8	8.7	12.8	13.3	5.1	3.5	4.6	4.2	3.9
1– 2	8.9	6.8	13.1	12.8	15.6	15.4	5.6	4.7	5.8	4.9	5.1
½– 1	11.2	7.0	18.0	16.6	17.3	14.4	7.2	6.9	7.4	6.6	9.0
¼– ½	9.9	7.0	19.1	16.1	13.5	10.9	2.0	6.2	7.4	6.7	12.7
⅛– ¼	2.3	2.4	6.4	5.5	4.8	3.0	2.7	2.7	2.4	2.0	4.4
Less than ⅛	2.0	1.8	2.7	2.2	2.6	2.0	2.4	1.9	1.3	1.4	2.5
Mean size in mm	5.53	7.71	1.65	2.09	1.93	2.40	13.0	15.1	11.9	12.4	6.11
Ratio deviation	6.87	6.13	5.00	5.18	4.64	4.18	7.07	8.53	7.96	7.41	8.14
Surface factor	0.56	0.46	0.97	0.84	0.83	0.67	0.43	0.44	0.41	0.39	0.67
Porosity per cent	18.0	19.1	17.7	25.0	24.8	28.3	23.0	16.5	16.4	16.8	18.8
Retention per cent	3.6	3.0	6.4	5.1	5.0	3.9	2.6	3.0	2.7	2.6	4.4
Specific yield per cent	14.4	16.1	11.3	19.9	19.8	24.4	20.4	13.5	13.7	14.2	14.4

Sample number	G298	G299	G300	*G301	*G302	*G304	*G305	*G306	*G307	*G308	*G309
Location number	F23	G23	G23	R15	R15	R15	R15	R15	R15	R15	P13
Diameter in millimeters	Percentages										
64–128	9.2	6.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32– 64	14.8	7.5	5.7	7.3	1.7	0.0	0.0	0.0	0.0	0.0	0.0
16– 32	16.3	7.8	8.8	14.5	9.4	0.0	0.0	0.0	0.0	0.0	0.0
8– 16	11.5	6.0	6.8	11.6	6.8	0.2	0.0	0.0	0.0	0 0	0.0
4– 8	7.1	5.3	6.4	3.6	2.6	0.8	0.0	0.0	0.0	0.0	0.1
2– 4	5.1	4.8	4.9	6.4	6.4	7.6	0.0	0.0	0.0	0.0	1.0
1– 2	6.2	11.1	9.9	12.1	16.8	32.2	0.0	0.0	0.2	0.5	14.9
½– 1	10.3	19.8	19.9	14.1	20.6	34.1	0.0	0.1	15.3	14.2	13.1
¼– ½	12.0	20.1	23.3	17.2	20.7	16.1	1.0	1.1	67.7	69.7	53.1
⅛– ¼	4.7	6.9	9.4	9.5	11.9	7.0	20.9	27.6	15.5	14.3	11.9
Less than ⅛	2.8	4.2	4.9	3.7	3.1	2.0	78.1	71.2	1.3	1 3	5.9
Mean size in mm.	5.22	1.92	1.30	2.02	1.13	0.78	**	**	0.35	0.35	0.41
Ratio deviation	7.89	7.43	5.85	6.60	4.87	2.22	-------	-------	1.52	1.51	2.09
Surface factor	0.71	1.12	1.31	1.08	1.23	1.07	-------	-------	1.81	1.80	1.89
Porosity per cent	21.7	32.0	29.3	33.1	28.0	34.6	40.4	40.1	42.3	39 1	34.5
Retention per cent	4.5	6.1	7.4	5.7	7.0	5.4	**	**	8.4	8.8	9.8
Specific yield per cent	17.2	25.9	21.9	27.4	21.0	29.2	-------	-------	33.9	30.3	24.7

*Marine material.
**In complete mechanical analysis; impossible to calculate statistical constants.

Sample number	*G310	*G311	*G312	G314	G315	G316	G317	*G318	*G319	*G320	*G321
Location number	P13	P13	N11	N16	N16	M14	M14	O9	O9	J6	J6
Diameter in millimeters	Percentages										
32– 64	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16– 32	0.0	0.0	0.0	1.0	1.1	0.3	0.4	0.0	0.0	0.0	0.0
8– 16	0.0	0.0	0.0	2.4	2.3	0.1	0.5	0.0	0.0	0.0	0.0
4– 8	0.3	10.6	1.0	3.4	3.9	0.4	0.5	0.0	0.0	0.3	0.5
2– 4	1.7	22.9	3.9	12.4	8.4	1.2	1.7	0.0	0.0	3.1	2.4
1– 2	18.2	28.8	13.2	26.3	20.2	10.4	9.2	0.0	0.0	8.2	9.0
½– 1	16.5	15.6	32.5	28.2	32.4	33.0	33.2	8.2	6.4	18.0	18.6
¼– ½	48.3	5.8	34.3	18.1	23.0	41.4	45.5	73.7	78.0	49.3	52.2
⅛– ¼	8.5	2.6	11.8	3.9	5.0	11.7	7.7	16.7	14.1	18.9	15.4
Less than ⅛	6.5	4.0	3.3	3.6	3.7	1.5	1.3	1.4	1.5	2.2	1.9
Mean size in mm.	0.46	1.35	0.52	0.96	0.81	0.49	0.51	0.33	0.33	0.41	0.43
Ratio deviation	2.19	2.61	2.20	2.94	2.83	2.01	2.03	1.45	1.42	2.04	2.00
Surface factor	1.80	0.81	1.53	1.08	1.20	1.47	1.39	1.90	1.88	1.76	1.68
Porosity per cent	34.2	28.3	32.0	36.5	37.9	41.6	39.6	38.6	37.0	31.2	32.0
Retention per cent	9.4	4.7	8.3	5.4	5.9	6.8	6.7	9.2	9.3	9.4	8.9
Specific yield per cent	24.8	23.6	23.7	31.1	32.0	34.8	32.9	29.4	27.7	21.8	23.1

Sample number	*G322	*G323	*G324	*G325	*G326	*G327	*G328	*G329	*G330	*G331	*G332
Location number	J6	J6	J6	J6	J6	J6	J6	J6	I7	I7	I7
Diameter in millimeters	Percentages										
32- 64	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.6	3.0	0.0
16- 32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.1	12.9	0.0
8- 16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.7	23.1	0.0
4- 8	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	8.8	14.4	0.0
2- 4	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	6.8	9.6	0.1
1- 2	0.7	0.9	0.0	0.0	0.1	1.5	0.1	0.1	18.5	16.0	0.7
½- 1	10.0	7.9	0.0	0.0	0.3	4.9	14.4	13.5	18.9	13.5	3.7
¼- ½	35.8	55.8	2.5	1.4	49.3	47.4	73.9	81.0	4.4	3.7	25.8
⅛- ¼	47.3	29.8	45.5	41.4	43.6	39.6	10.3	4.3	1.2	1.4	42.1
Less than ⅛	6.2	5.6	52.0	57.2	6.7	6.0	1.3	1.1	2.0	2.4	27.6
Mean size in mm.	0.25	0.28	**	**	0.24	0.27	0.36	0.37	3.47	3.72	**
Ratio deviation	1.72	1.66	-------	-------	1.54	1.74	1.47	1.38	4.76	4.29	-------
Surface factor	2.69	2.38	-------	-------	2.75	2.58	1.74	1.63	0.54	0.53	-------
Porosity per cent	39.0	39.5	45.8	41.7	43.4	36.6	41.6	35.9	27.8	25.8	41.6
Retention per cent	12.8	11.3	**	**	12.2	12.8	7.9	8.3	3.1	3.1	**
Specific yield per cent	26.2	28.2	-------	-------	31 2	23.8	33.7	27.6	24 7	22.7	-------

*Marine material.
**Incomplete mechanical analysis; impossible to calculate statistical constants.

Sample number	*G333	G335	G336	G337	G338
Location number	I7	F8	F8	F8	F8
Diameter in millimeters	Percentages				
4- 8	0.0	0.1	0.0	0.0	0.0
2- 4	0.1	0.8	0.1	0.1	0.0
1- 2	0.9	10.2	5.0	5.2	0.0
½- 1	5.4	38.1	35.5	33.1	0.0
¼- ½	25.6	33.0	40.0	42.5	14.7
⅛- ¼	45.2	11.3	12.6	12.3	45.1
Less than ⅛	22.8	6.5	6.8	6.8	40.2
Mean size in mm.	**	0.46	0.41	0.40	**
Ratio deviation	-------	2.08	1.95	1.93	-------
Surface factor	-------	1.78	1.92	1.93	-------
Porosity per cent	38.7	36.3	42.1	40.3	44.7
Retention per cent	**	9.0	8.8	9.2	**
Specific yield per cent	-------	27.3	33.3	31.1	-------

*Marine material.
**Incomplete mechanical analysis· impossible to calculate statistical constants.

PUBLICATIONS

DIVISION OF WATER RESOURCES

PUBLICATIONS OF THE

DIVISION OF WATER RESOURCES

DEPARTMENT OF PUBLIC WORKS

STATE OF CALIFORNIA

When the Department of Public Works was created in July, 1921, the State Water Commission was succeeded by the Division of Water Rights, and the Department of Engineering was succeeded by the Division of Engineering and Irrigation in all duties except those pertaining to State Architect. Both the Division of Water Rights and the Division of Engineering and Irrigation functioned until August, 1929, when they were consolidated to form the Division of Water Resources.

STATE WATER COMMISSION

First Report, State Water Commission, March 24 to November 1, 1912.
Second Report State Water Commission, November 1, 1912, to April 1, 1914.
*Biennial Report, State Water Commission, March 1, 1915, to December 1, 1916.
Biennial Report, State Water Commission, December 1, 1916, to September 1, 1918.
Biennial Report, State Water Commission, September 1, 1918, to September 1, 1920.

DIVISION OF WATER RIGHTS

*Bulletin No. 1—Hydrographic Investigation of San Joaquin River, 1920–1923.
*Bulletin No. 2—Kings River Investigation, Water Master's Report, 1918–1923.
*Bulletin No. 3—Proceedings First Sacramento-San Joaquin River Problems Conference, 1924.
*Bulletin No. 4—Proceedings Second Sacramento-San Joaquin River Problems Conference. and Water Supervisors' Report, 1924.
*Bulletin No. 5—San Gabriel Investigation—Basic Data, 1923–1926.
Bulletin No. 6—San Gabriel Investigation—Basic Data, 1926–1928.
Bulletin No. 7—San Gabriel Investigation—Analysis and Conclusions, 1929.
*Biennial Report, Division of Water Rights, 1920–1922.
*Biennial Report, Division of Water Rights, 1922–1924.
Biennial Report, Division of Water Rights, 1924–1926.
Biennial Report, Division of Water Rights, 1926–1928.

DEPARTMENT OF ENGINEERING

*Bulletin No. 1—Cooperative Irrigation Investigations in California, 1912–1914.
*Bulletin No. 2—Irrigation Districts in California, 1887–1915.
Bulletin No. 3—Investigations of Economic Duty of Water for Alfalfa in Sacramento Valley, California, 1915.
*Bulletin No. 4—Preliminary Report on Conservation and Control of Flood Waters in Coachella Valley, California, 1917.
*Bulletin No. 5—Report on the Utilization of Mohave River for Irrigation in Victor Valley, California, 1918.
*Bulletin No. 6—California Irrigation District Laws, 1919 (now obsolete).
Bulletin No. 7—Use of Water from Kings River, California, 1918.
*Bulletin No. 8—Flood Problems of the Calaveras River, 1919.
Bulletin No. 9—Water Resources of Kern River and Adjacent Streams and Their Utilization, 1920.
*Biennial Report, Department of Engineering, 1907–1908.
*Biennial Report, Department of Engineering, 1908–1910.
*Biennial Report, Department of Engineering, 1910–1912.
*Biennial Report, Department of Engineering, 1912–1914.
*Biennial Report, Department of Engineering, 1914–1916.
*Biennial Report, Department of Engineering, 1916–1918.
*Biennial Report, Department of Engineering, 1918–1920.

* Reports and Bulletins out of print. These may be borrowed by your local library from the California State Library at Sacramento, California.

DIVISION OF WATER RESOURCES

Including Reports of the Former Division of Engineering and Irrigation

*Bulletin No. 1—California Irrigation District Laws, 1921 (now obsolete).
*Bulletin No. 2—Formation of Irrigation Districts, Issuance of Bonds, etc., 1922.
Bulletin No. 3—Water Resources of Tulare County and Their Utilization, 1922.
Bulletin No. 4—Water Resources of California, 1923.
Bulletin No. 5—Flow in California Streams, 1923.
Bulletin No. 6—Irrigation Requirements of California Lands, 1923.
*Bulletin No. 7—California Irrigation District Laws, 1923 (now obsolete).
*Bulletin No. 8—Cost of Water to Irrigators in California, 1925.
Bulletin No. 9—Supplemental Report on Water Resources of California, 1925.
*Bulletin No. 10—California Irrigation District Laws, 1925 (now obsolete).
Bulletin No. 11—Ground Water Resources of Southern San Joaquin Valley, 1927.
Bulletin No. 12—Summary Report on the Water Resources of California and a Coordinated Plan for Their Development, 1927.
Bulletin No. 13—The Development of the Upper Sacramento River, containing U. S. R. S. Cooperative Report on Iron Canyon Project, 1927.
Bulletin No. 14—The Control of Floods by Reservoirs, 1928.
*Bulletin No. 18—California Irrigation District Laws, 1927 (now obsolete).
*Bulletin No. 18-A—California Irrigation District Laws, 1929, Revision (now obsolete).
Bulletin No. 18-B—California Irrigation District Laws, 1931, Revision.
Bulletin No. 18-C—California Irrigation District Laws, 1933, Revision.
Bulletin No. 19—Santa Ana Investigation, Flood Control and Conservation (with packet of maps), 1928.
Bulletin No. 20—Kennett Reservoir Development, an Analysis of Methods and Extent of Financing by Electric Power Revenue, 1929.
Bulletin No. 21—Irrigation Districts in California, 1929.
Bulletin No. 21-A—Report on Irrigation Districts in California for the year 1929.
Bulletin No. 21-B—Report on Irrigation Districts in California for the year 1930.
Bulletin No. 21-C—Report on Irrigation Districts in California for the year 1931. (Mimeographed.)
Bulletin No. 21-D—Report on Irrigation Districts in California for the year 1932. (Mimeographed.)
Bulletin No. 21-E—Report on Irrigation Districts in California for the year 1933. (Mimeographed.)
Bulletin No. 22—Report on Salt Water Barrier (two volumes), 1929.
Bulletin No. 23—Report of Sacramento-San Joaquin Water Supervisor, 1924–1928.
Bulletin No. 24—A Proposed Major Development on American River, 1929.
Bulletin No. 25—Report to Legislature of 1931 on State Water Plan, 1930.
Bulletin No. 26—Sacramento River Basin, 1931.
Bulletin No. 27—Variation and Control of Salinity in Sacramento-San Joaquin Delta and Upper San Francisco Bay, 1931.
Bulletin No. 28—Economic Aspects of a Salt Water Barrier Below Confluence of Sacramento and San Joaquin Rivers, 1931.
Bulletin No. 28-A—Industrial Survey of Upper San Francisco Bay Area, 1930.
Bulletin No. 29—San Joaquin River Basin, 1931.
Bulletin No. 31—Santa Ana River Basin, 1930.
Bulletin No. 32—South Coastal Basin, a Cooperative Symposium, 1930.
Bulletin No. 33—Rainfall Penetration and Consumptive Use of Water in Santa Ana River Valley and Coastal Plain, 1930.
Bulletin No. 34—Permissible Annual Charges for Irrigation Water in Upper San Joaquin Valley, 1930.
Bulletin No. 35—Permissible Economic Rate of Irrigation Development in California, 1930.
Bulletin No. 36—Cost of Irrigation Water in California, 1930.
Bulletin No. 37—Financial and General Data Pertaining to Irrigation, Reclamation and Other Public Districts in California, 1930.
Bulletin No. 38—Report of Kings River Water Master for the Period 1918–1930.
Bulleain No. 39—South Coastal Basin Investigation, Records of Ground Water Levels at Wells, 1932.
Bulletin No. 39-A—Records of Ground Water Levels at Wells for the Year 1932, Seasonal Precipitation Records to and including 1931–32. (Mimeographed)
Bulletin No. 39-B—Records of Ground Water Levels at Wells for the Year 1933, Precipitation Records for the Season 1932–33. (Mimeographed)

* Reports and Bulletins out of print. These may be borrowed by your local library from the California State Library at Sacramento, California.

Bulletin No. 40—South Coastal Basin Investigation, Quality of Irrigation Waters, 1933.

Bulletin No. 41—Pit River Investigation, 1933.

Bulletin No. 42—Santa Clara Investigation, 1933.

Bulletin No. 43—Value and Cost of Water for Irrigation in Coastal Plain of Southern California, 1933.

Bulletin No. 44—Water Losses Under Natural Conditions from Wet Areas in Southern California, 1933.

Bulletin No. 45—South Coastal Basin Investigation, Geology and Ground Water Storage Capacity of Valley Fill, 1934.

Bulletin No. 46—Ventura County Investigation, 1933.

Bulletin No. 46-A—Ventura County Investigation, Basic Data for the Period 1927 to 1932 inclusive. (Mimeographed)

Bulletin No. 47—Mojave River Investigation, 1934. (Mimeographed)

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PAMPHLETS

Act Governing Supervision of Dams in California, with Revised Rules and Regulations, 1933.

Water Commission Act with Amendments Thereto, 1933.

Rules, Regulations and Information Pertaining to Appropriation of Water in California, 1933.

Rules and Regulations Governing the Determination of Rights to Use of Water in Accordance with the Water Commission Act, 1925.

Tables of Discharge for Parshall Measuring Flumes, 1928.

General Plans, Specifications and Bills of Material for Six and Nine Inch Parshall Measuring Flumes, 1930.

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*Report of the Conservation Commission of California, 1912.

*Irrigation Resources of California and Their Utilization (Bul. 254, Office of Exp. U. S. D. A.) 1913.

*Report, State Water Problems Conference, November 25, 1916.

*Report on Pit River Basin, April, 1915.

*Report on Lower Pit River Project, July, 1915.

*Report on Iron Canyon Project, 1914.

*Report on Iron Canyon Project, California, May, 1920.

*Sacramento Flood Control Project (Revised Plans), 1925.

Report of Commission Appointed to Investigate Causes Leading to the Failure of St. Francis Dam, 1928.

Report of the California Joint Federal-State Water Resources Commission, 1930.

Conclusions and Recommendations of the Report of the California Irrigation and Reclamation Financing and Refinancing Commission, 1930.

*Report of California Water Resources Commission to the Governor of California on State Water Plan, 1932.

*Booklet of Information on California and the State Water Plan prepared for United States House of Representatives' Subcommittee on Appropriations, 1931.

*Bulletin on Great Central Valley Project of State Water Plan of California Prepared for United States Senate Committee on Irrigation and Reclamation, 1932.

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* Reports and Bulletins out of print. These may be borrowed by your local library from the California State Library at Sacramento, California.

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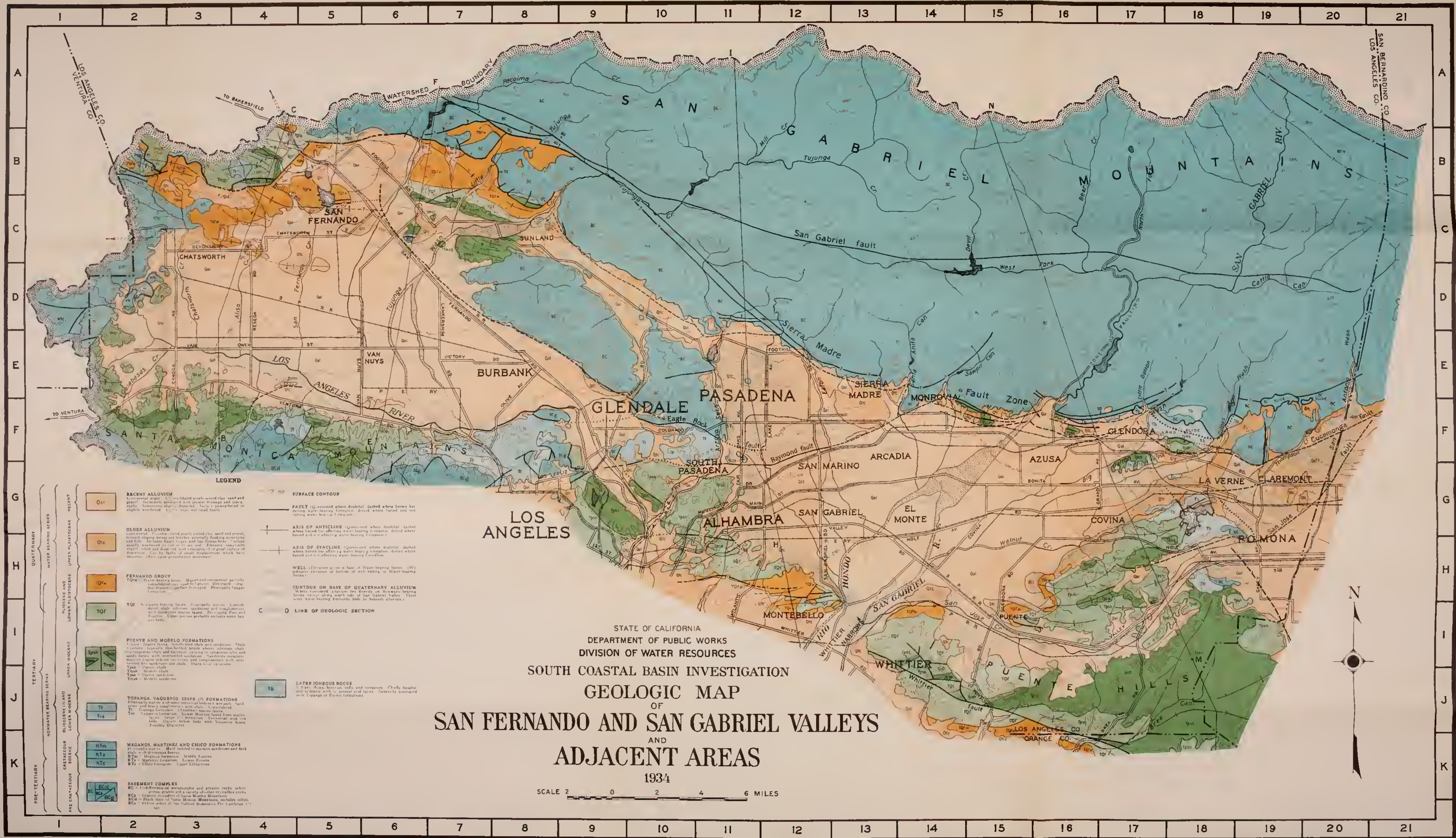
MAPS IN POCKET

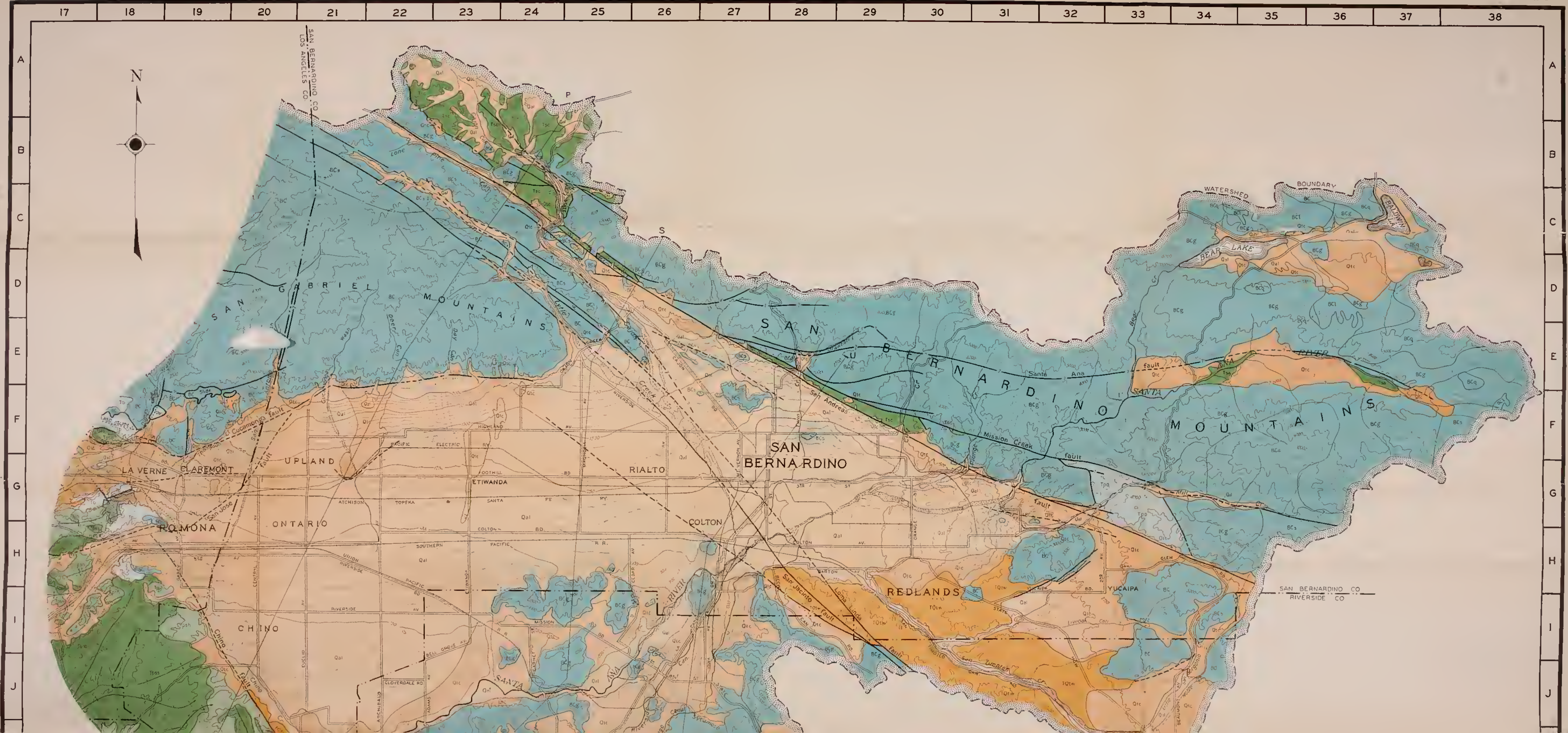


STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF WATER RESOURCES
SOUTH COASTAL BASIN INVESTIGATION
GEOLOGIC MAP
OF
SAN FERNANDO AND SAN GABRIEL VALLEYS
AND
ADJACENT AREAS
1934
SCALE 2 0 2 4 6 MILES
LEGEND
RECENT ALLUVIUM
OLDER ALLUVIUM
FERNANDO GROUP
PUENTE AND MODELO FORMATIONS
TOPANGA, VAQUEROS, SESPE (?) FORMATIONS
MEGANOS, MARTINEZ AND CHICO FORMATIONS
BASEMENT COMPLEX
LATER IGNEOUS ROCKS
SURFACE CONTOUR
FAULT
AXIS OF ANTICLINE
AXIS OF SYNCLINE
WELL
CONTOUR ON BASE OF QUATERNARY ALLUVIUM
LINE OF GEOLOGIC SECTION
QUATERNARY
TERTIARY
PRE-TERTIARY
WATER BEARING SERIES
NONWATER BEARING SERIES
SAN GABRIEL MOUNTAINS
SANTA MONICA MOUNTAINS
PUENTE HILLS
SAN FERNANDO
CHATSWORTH
VAN NUYS
BURBANK
SUNLAND
GLENDALE
PASADENA
SOUTH PASADENA
LOS ANGELES
ALHAMBRA
SAN MARINO
SAN GABRIEL
ARCADIA
SIERRA MADRE
MONROVIA
AZUSA
GLENDORA
LA VERNE
CLAREMONT
COVINA
POMONA
EL MONTE
MONTEBELLO
WHITTIER
PUENTE
LOS ANGELES RIVER
San Gabriel fault
Sierra Madre Fault Zone
Raymond fault
LOS ANGELES CO.
VENTURA CO.
SAN BERNARDINO CO.
ORANGE CO.
WATERSHED BOUNDARY
TO BAKERSFIELD
TO VENTURA

PLATE B


STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF WATER RESOURCES
SOUTH COASTAL BASIN INVESTIGATION
GEOLOGIC MAP
OF
COASTAL PLAIN
AND
ADJACENT AREAS
1934
SCALE 2 0 2 4 6 MILES
LEGEND
LOS ANGELES
SANTA MONICA MTS
BEVERLY HILLS
ALHAMBRA
SOUTH PASADENA
MONTEBELLO
SANTA MONICA
CULVER CITY
VENICE
VERNON
HUNTINGTON PARK
BELL
MAYWOOD
WHITTIER
PUENTE HILLS
INGLEWOOD
SOUTHGATE
LYNWOOD
EL SEGUNDO
HAWTHORNE
GARDENA
COMPTON
MANHATTAN BEACH
HERMOSA BEACH
REDONDO BEACH
TORRANCE
NORWALK
SANTA FE SPRINGS
LA HABRA
BREA
COYOTE HILLS
FULLERTON
PLACENTIA
ANAHEIM
STANTON
ORANGE
SANTA ANA
TUSTIN
SANTA ANA MOUNTAINS
L.A.
SAN PEDRO HILLS
SAN PEDRO
LOS ANGELES HARBOR
LONG BEACH
SIGNAL HILL
SAN PEDRO BAY
SEAL BEACH
HUNTINGTON BEACH
NEWPORT BEACH
SAN JOAQUIN HILLS
EL TORO
WATERSHED BOUNDARY
N

PLATE C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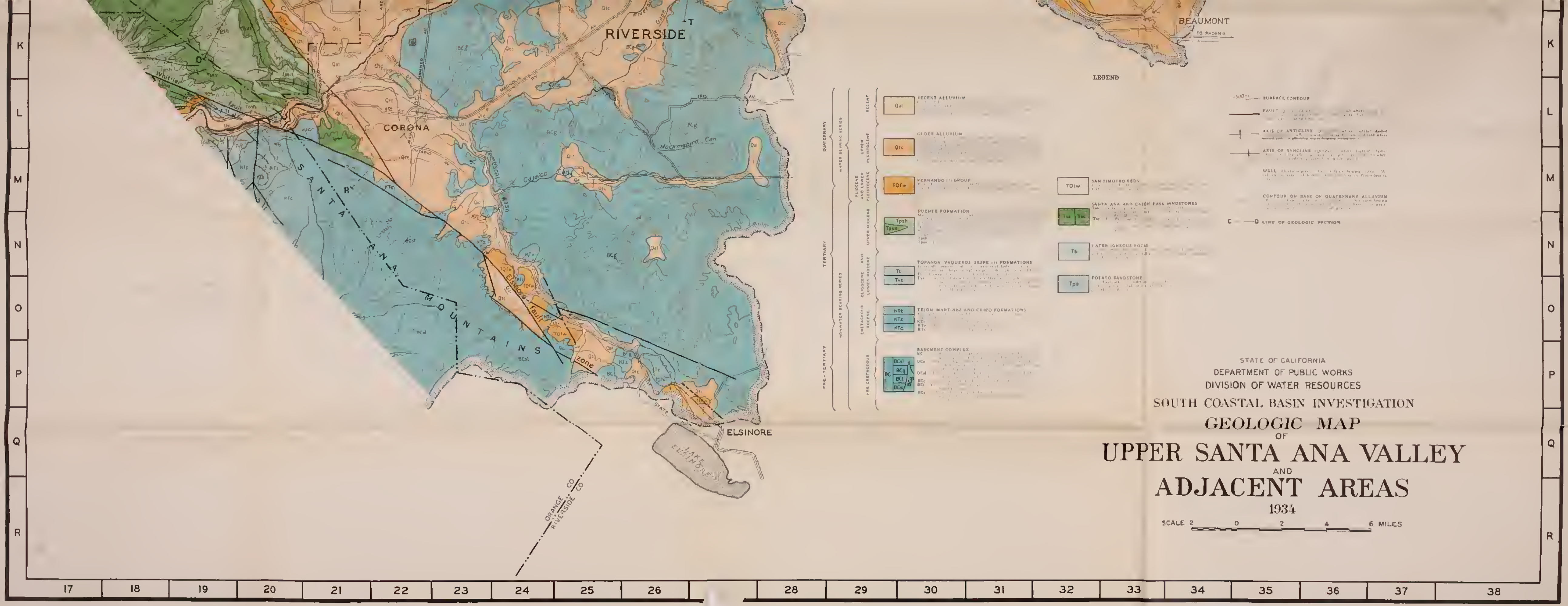
SAN BERNARDINO CO
LOS ANGELES CO
SAN GABRIEL MOUNTAINS
SAN BERNARDINO MOUNTAINS
WATERSHED BOUNDARY
BEAR LAKE
BALDWIN
Santa Ana
SANTA ANA RIVER
fault
San Andreas
Mission Creek
Cucamonga fault
San Jose
LA VERNE
CLAREMONT
UPLAND
POMONA
ONTARIO
CHINO
ETIWANDA
RIALTO
SAN BERNARDINO
COLTON
REDLANDS
YUCAIPA
San Jacinto fault
Loma Linda
HIGHLAND AV.
PACIFIC ELECTRIC RY.
FOOTHILL BD.
ATCHISON TOPEKA & SANTA FE RY.
COLTON BD.
SOUTHERN PACIFIC R.R.
UNION PACIFIC RR.
RIVERSIDE
SAN BERNARDINO CO
RIVERSIDE CO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CORONA
BEAUMONT
TO PHOENIX
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LAKE ELSINORE
SANTA ANA MOUNTAINS
Elsinore fault zone
Whittier
ORANGE CO
RIVERSIDE CO
Mockingbird Can
Calico
Temescal Wash
LEGEND
RECENT ALLUVIUM
OLDER ALLUVIUM
FERNANDO (?) GROUP
PUENTE FORMATION
TOPANGA VAQUEROS SESPE (?) FORMATIONS
TEJON MARTINEZ AND CHICO FORMATIONS
BASEMENT COMPLEX
SAN TIMOTEO BEDS
SANTA ANA AND CAJON PASS SANDSTONES
LATER IGNEOUS ROCKS
POTATO SANDSTONE
SURFACE CONTOUR
FAULT
AXIS OF ANTICLINE
AXIS OF SYNCLINE
WELL
CONTOUR ON BASE OF QUATERNARY ALLUVIUM
LINE OF GEOLOGIC SECTION
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PRE-TERTIARY
WATER BEARING SERIES
NONWATER BEARING SERIES
RECENT
UPPER PLEISTOCENE
PLIOCENE AND LOWER PLEISTOCENE
UPPER MIOCENE
OLIGOCENE AND LOWER MIOCENE
CRETACEOUS EOCENE
PRE CRETACEOUS
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Tpsh
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BCsl
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STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF WATER RESOURCES
SOUTH COASTAL BASIN INVESTIGATION
GEOLOGIC MAP
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UPPER SANTA ANA VALLEY
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1934
SCALE 2 0 2 4 6 MILES
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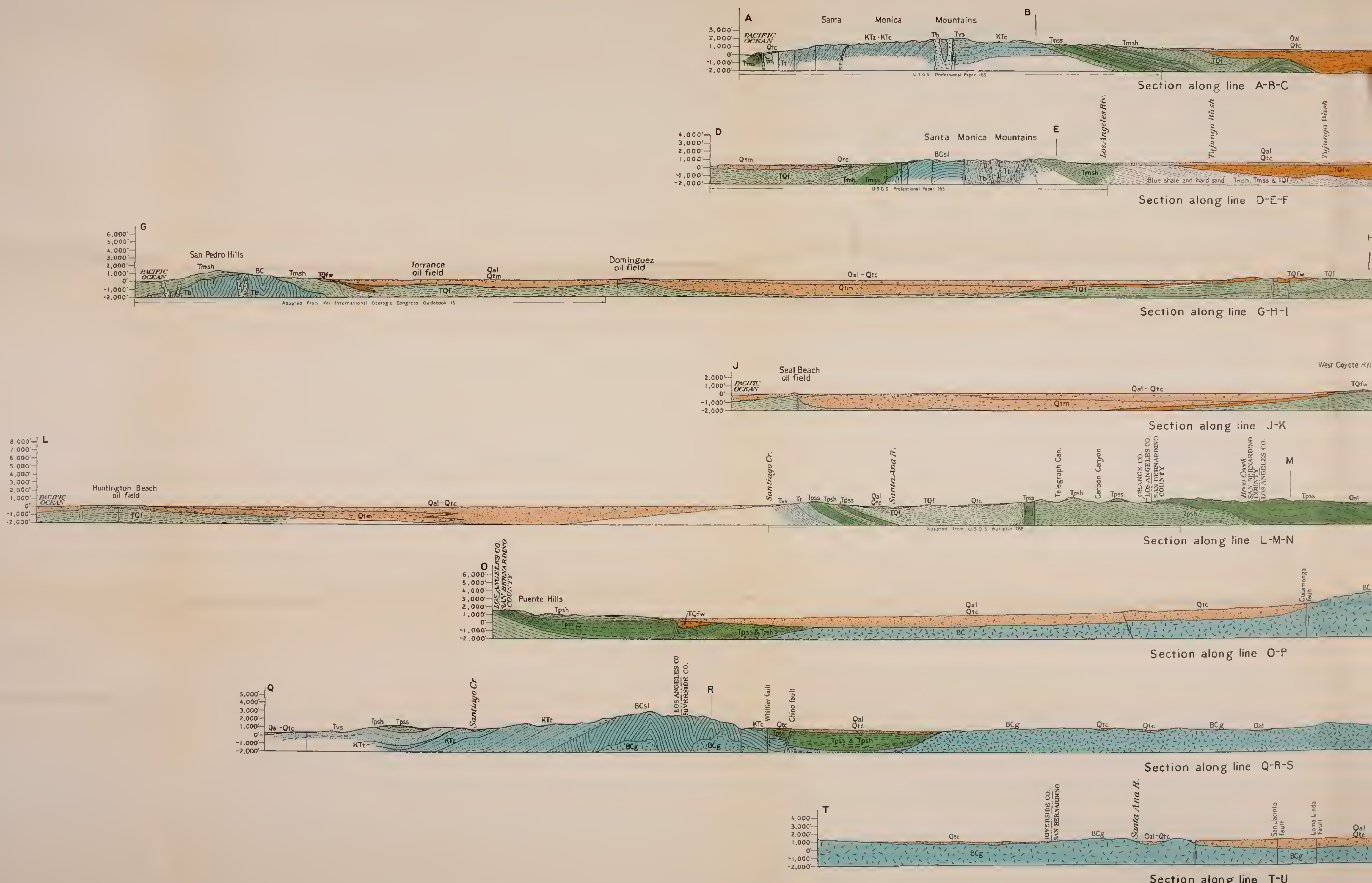
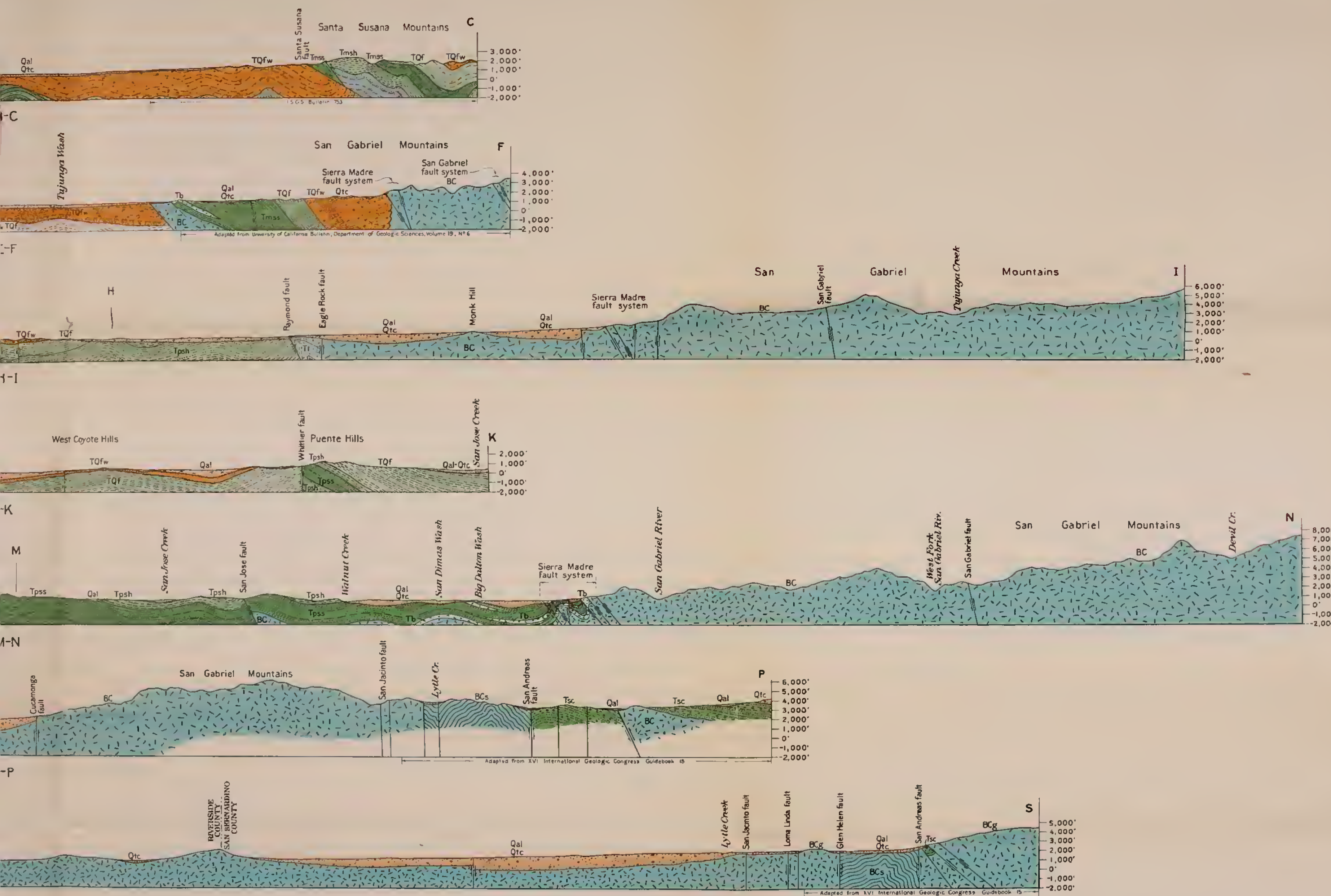
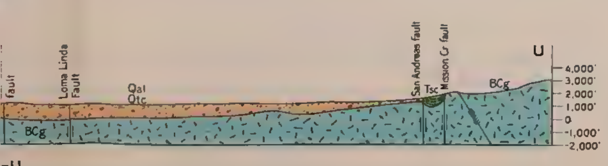


A
Santa Monica Mountains
B
PACIFIC OCEAN
Section along line A-B-C
D
Santa Monica Mountains
E
Los Angeles Riv.
Tujunga Wash
Tujunga Wash
Blue shale and hard sand Tmsh, Tmss & TQf
Section along line D-E-F
G
San Pedro Hills
Torrance oil field
Dominguez oil field
PACIFIC OCEAN
Qal - Qtc
Section along line G-H-I
J
Seal Beach oil field
PACIFIC OCEAN
West Coyote Hill
Qal - Qtc
Section along line J-K
L
Huntington Beach oil field
PACIFIC OCEAN
Qal - Qtc
Santiago Cr.
Santa Ana R.
Telegraph Can.
Carbon Canyon
ORANGE CO.
LOS ANGELES CO.
SAN BERNARDINO COUNTY
Brea Creek
M
Section along line L-M-N
O
LOS ANGELES CO.
SAN BERNARDINO COUNTY
Puente Hills
Cucamonga fault
Section along line O-P
Q
Santiago Cr.
LOS ANGELES CO.
RIVERSIDE CO.
R
Whittier fault
Chino fault
Tpss & Tpsh
Section along line Q-R-S
T
RIVERSIDE CO.
SAN BERNARDINO
Santa Ana R.
San Jacinto fault
Loma Linda fault
Section along line T-U





LEGEND

Qal - Recent alluvium. Qtc - Older alluvium. Qtm - Undeformed and slightly deformed marine beds, terrace and other deposits (includes Palos Verdes sand). TQfw - Fernando Group, water-bearing facies (includes San Pedro beds). TQf - Fernando Group, nonwater-bearing facies, (probably includes San Pedro beds). Tmsh - Modelo shale. Tmss - Modelo sandstone. Tpsh - Puente shale. Tpss - Puente sandstone. Tsc - Sandstones of Cajon Pass area. Tb - Later igneous rocks. Tt - Topanga formation. Tvs - Vaqueros-Sespe(?) formations. KTt - Tejon formation. KTz - Martinez formation. KTc - Chico formation. BC - Undifferentiated Basement Complex. BCg - Granitic intrusives. BCsl - Slate series. BCs - Pelona schist.

Note: For lines of sections see accompanying geologic maps

STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF WATER RESOURCES

SOUTH COASTAL BASIN INVESTIGATION

GEOLOGIC SECTIONS

SCALE

1 0 1 2 3 4 MILES


SAN GABRIEL MOUNTAINS
SANTA MONICA MOUNTAINS
LOS ANGELES
SANTA MONICA BAY
SAN PEDRO BAY
SAN PEDRO HILLS
SAN JOAQUIN HILLS
SAN JOSE HILLS
PUENTE HILLS
LOS ANGELES CO.
VENTURA CO.
SAN BERNARDINO CO.
LOS ANGELES CO.
ORANGE CO.
SAN FERNANDO
TUJUNGA
CRESCENTA
VAN NUYS
BURBANK
GLENDALE
PASADENA
SIERRA MADRE
MONROVIA
ARCADIA
AZUSA
GLENDORA
LA VERNE
CLAREMONT
UPLAND
POMONA
ONTARIO
CHINO
CORONA
SAN MARINO
SAN GABRIEL
ALHAMBRA
EL MONTE
BALDWIN PARK
COVINA
PUENTE
HOLLYWOOD
BEVERLY HILLS
SAWTELLE
CULVER CITY
SANTA MONICA
OCEAN PARK
VENICE
MONTEBELLO
VERNON
HUNTINGTON PARK
SOUTHGATE
WHITTIER
INGLEWOOD
DOWNEY
LYNWOOD
LA HABRA
BREA
FULLERTON
EL SEGUNDO
MANHATTAN BEACH
HERMOSA BEACH
REDONDO BEACH
GARDENA
COMPTON
TORRANCE
SIGNAL HILL
LONG BEACH
SAN PEDRO
LOS ANGELES HARBOR
SEAL BEACH
ANAHEIM
ORANGE
SANTA ANA
TUSTIN
HUNTINGTON BEACH
NEWPORT BEACH
LEGEND
NONWATER-BEARING AREA
AREA OF FOLDED WATER-BEARING BEDS
BASIN DIVISION
APPROXIMATE BOUNDARY OF AREA OF NO STORAGE CHANGE
CONTOUR OF GROUND WATER TABLE, JANUARY, 1933
LINE OF EQUAL SPECIFIC YIELD FOR A ZONE AVERAGING 50 FEET EACH WAY FROM WATER TABLE OF JANUARY 1933.
ESTIMATED WITHOUT WELL LOG DATA
WELL LOCATION

PLATE E

SAN BERNARDINO MOUNTAINS
SAN BERNARDINO
FONTANA
RIALTO
COLTON
REDLANDS
ONTARIO
RIVERSIDE
CORONA
YUCAIPA
BEAUMONT
SANTA ANA RIVER
BEAR LAKE
LAKE ELSINORE
SAN BERNARDINO CO
RIVERSIDE CO
WATERSHED BOUNDARY
GROUND WATER BASINS
SAN FERNANDO VALLEY
1 SAN FERNANDO
2 SYLMAR
3 TUJUNGA
4 PACOIMA
5 VERDUGO
SAN GABRIEL VALLEY
6 MAIN SAN GABRIEL
7 MONK HILL
8 RAYMOND 8a PASADENA AREA 8b SANTA ANITA AREA
9 UPPER CANYON
10 LOWER CANYON
11 GLENDORA
12 WAY HILL
13 SAN DIMAS
14 FOOTHILL
15 PUENTE
UPPER SANTA ANA VALLEY
16 CHINO
17 CLAREMONT HEIGHTS
18 LIVEOAK
19 POMONA
20 CUCAMONGA
21 RIALTO-COLTON 21a RIALTO 21b COLTON
22 BUNKER HILL
23 LYTLE
24 DEVIL CANYON
25 YUCAIPA-BEAUMONT 25a YUCAIPA 25b BEAUMONT
26 SAN TIMOTEO 26a NORTH AREA 26b SOUTH AREA
27 RIVERSIDE
28 ARLINGTON
29 TEMESCAL
30 SPADRA
COASTAL PLAIN
31 WEST 31a NORTHERN AREA 31b SOUTHERN AREA
32 HOLLYWOOD
33 CENTRAL 33a LOS ANGELES RIVER AREA 33b SAN GABRIEL RIVER AREA 33c SANTA ANA RIVER AREA 33d IRVINE AREA
34 LA HABRA
35 YORBA LINDA
36 LOS ANGELES NARROWS
37 SANTA ANA NARROWS
MISCELLANEOUS
38 BULL CANYON
39 LITTLE TUJUNGA
40 LOWER CAJON
41 UPPER CAJON
42 BEAR VALLEY
43 BIG MEADOWS
44 SEVEN OAKS
45 RECHE CANYON
46 CAJALCO
47 LEE LAKE
48 COLDWATER
49 BEDFORD
50 SANTIAGO
NOT INCLUDED IN STUDY
STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF WATER RESOURCES
SOUTH COASTAL BASIN INVESTIGATION
SPECIFIC YIELDS IN GROUND WATER BASINS
SCALE
MILES 0 5 10 15 20 MILES
FEET 5000 0 25000 50000 75000 100000 FEET
1934


SAN GABRIEL MOUNTAINS
SANTA MONICA MOUNTAINS
LOS ANGELES
SANTA MONICA BAY
SAN PEDRO BAY
SAN PEDRO HILLS
SAN JOAQUIN HILLS
SAN JOSE HILLS
PUENTE HILLS
SAN FERNANDO
VAN NUYS
BURBANK
GLENDALE
LA CRESCENTA
PASADENA
SIERRA MADRE
MONROVIA
ARCADIA
SAN MARINO
SAN GABRIEL
ALHAMBRA
EL MONTE
BALDWIN PARK
AZUSA
GLENDORA
COVINA
LA VERNE
CLAREMONT
UPLAND
POMONA
CHINO
HOLLYWOOD
BEVERLY HILLS
SAWTELLE
CULVER CITY
SANTA MONICA
OCEAN PARK
VENICE
INGLEWOOD
EL SEGUNDO
MANHATTAN BEACH
HERMOSA BEACH
REDONDO BEACH
TORRANCE
GARDENA
COMPTON
LYNWOOD
SOUTHGATE
HUNTINGTON PARK
VERNON
MONTEBELLO
WHITTIER
DOWNEY
SANTA FE SPRINGS
LA HABRA
BREA
FULLERTON
ANAHEIM
ORANGE
SANTA ANA
TUSTIN
SIGNAL HILL
LONG BEACH
SAN PEDRO
LOS ANGELES HARBOR
SEAL BEACH
HUNTINGTON BEACH
NEWPORT BEACH
WATERSHED BOUNDARY
LOS ANGELES CO
VENTURA CO
SAN BERNARDINO CO
ORANGE CO
N

PLATE F

LEGEND

—10— LINE OF EQUAL SPECIFIC YIELD OF UNWEATHERED GRAVELS. ESTIMATED FROM SURFACE AND WELL SAMPLE DATA. MINIMUM VALUE ASSIGNED IS 13 PER CENT.

o G-204 LOCATION AND SAMPLE NUMBER. SAMPLE TAKEN FROM UNDISTURBED CLAY, GRAVEL OR SAND BED.

o F-8 LOCATION AND NUMBER OF POST HOLE OR PIT FROM WHICH SAMPLES OF UNDISTURBED SEDIMENTS WERE EXTRACTED.

STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF WATER RESOURCES

SOUTH COASTAL BASIN INVESTIGATION

SPECIFIC YIELD OF UNWEATHERED GRAVELS

SCALE

MILES 0 5 10 15 20 MILES

FEET 5000 0 25000 50000 75000 100000 FEET